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AMRL-TR-76-84

A PRIMARY AUDITORY NERVE MODEL

UNIVERSITY OF DAYTON RESEARCH INSTITUTE
DAYTON, OHIO 45469

OCTOBER 1976

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FOR THE COMMANDER

HENNING E. VON GIERKE
Director
Biodynamics and Bionics Division
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AIR FORCE - 20 DECEMBER 76 - 100

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
AMRL-TR-76-84		

UDRI-TR-76-17

4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED
A Primary Auditory Nerve Model.	Final Report 75 Mar 01 - 76 Jan 30
	6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)	8. CONTRACT OR GRANT NUMBER(s)
Duane G. Leet	F33615-75-C-5098

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
University of Dayton Research Institute 300 College Park Avenue Dayton, Ohio 45469	61102F 7232 02-15

11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE
Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433	October 1976
	13. NUMBER OF PAGES
	186

187 p.

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report)
	Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

Final rept. 1 Mar 75 - 30 Jan 76,

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, If different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Bionics
Auditory System
Primary Auditory Nerve
Cochlea
Syncoder

Speech
Neurocybernetics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A model of the auditory system from the middle ear through the primary auditory nerve has been developed. It is comprised of an electronic analog device developed by James C. Rock called ROC COC and a pair of components simulated in FORTRAN called TM and BSS. Procedures have been developed for obtaining the parameter values of TM and BSS from the available neurophysiological data. → next page

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Block 20 (Continued)

Five different parameter value sets were used to provide the five different model candidates to be compared with a 1263 Hz CF primary auditory neuron of a guinea pig. Pure-tone and speech-like stimuli originally presented to the neuron were presented to each of the five models. Selection of the best model was based on a qualitative evaluation of PIH shapes and a quantitative analysis of the number of peaks that matched between corresponding model and neuron PIHs.

The best model was presented with several more pure-tone and speech-like stimuli previously presented to the neuron. Corresponding vowel-PIHs of the model and neuron generated from the responses to these stimuli were compared using the fraction of misplaced peaks metric. Using benchmark values obtained by comparing different neuron vowel-PIHs generated from responses to approximately the same intensity, it was determined that the model produced vowel-PIHs that fell within the benchmark for six or seven of the ten vowel sounds used.

It was found that the peaks in stimulus zero-crossing interval histograms could be used to predict the peak occurrences in model and neuron vowel PIHs. The prediction was more accurate for the model than for the neuron. It was also more accurate for those vowels that have formants close to the characteristic frequency of the neuron.

cont →

Information generated from study of this and future versions of the model will be incorporated into the development of speech recognition systems based upon the performance characteristics of the auditory nervous system. Such systems would be a valuable tool to the Air Force in the fields of intelligence, communications and man-machine interface.

SUMMARY

A model of the peripheral auditory system, up to and including the primary auditory nerve, is in an advanced stage of development. The model is comprised of an analog electronic device, the ROC COC Analog Cochlea, that simulates the temporal and relative magnitude transform of the middle and inner ear, and a FORTRAN program system that simulates the primary auditory nerve and the absolute magnitude transform of the entire peripheral auditory system.

The ROC COC's middle ear circuit is an active bandpass filter with a center frequency of about 1.8 kHz and a bandwidth of about 3 kHz. The ROC COC's cochlea section is a transmission line comprised of a cascade of lowpass filters. Each filter is tapped to provide an output voltage analogous to the displacement at a point on the cochlea's basilar membrane.

The model of the primary auditory nerve is called the Basic Stochastic Syncoder. It is a binary threshold device with the threshold function $F(i\Delta) = \varphi + \theta \exp[B \cdot (j-1)\Delta]$, where B is a random variable called the decay rate, with probability density function $p_B(.)$, j is the time interval when the syncoder last fired, Δ is the sample interval, and φ and θ are parameters. The threshold function is compared at each time interval with the syncoder's summation potential $q(i\Delta) = \min\{\alpha_x \cdot x(i\Delta - \tau_x\Delta), q_{max}\}$, where $x(.)$ is the syncoder's stimulus and q_{max}, α_x, and τ_x are parameters. At any sample interval, except those falling within the syncoder's absolute refractory period, the syncoder will generate a one response if the threshold function value is not greater than the summation potential value:

$$Y(i\Delta) = \begin{cases} 1 & \text{iff } q(i\Delta) \geq F(i\Delta) \text{ and } i-j > \rho/\Delta \\ 0 & \text{otherwise} \end{cases}$$

where is the absolute refractory period. At that instant the threshold function is reset to its maximum value, a new decay rate value B is chosen according to $p_B(.)$, and the threshold function begins its decay.

In earlier neurophysiological experiments, pure-tone stimuli and speech-like stimuli comprised of sequences of five vowel sounds were presented to the middle ear of guinea pigs and the response of the primary auditory neurons recorded. These data are the standard of comparison for the model's development and verification.

Both theoretical and empirical studies of the model's behavioral characteristics were performed. From these studies procedures were developed for estimating the model's parameter values from the available neurophysiological data.

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Five different parameter value sets were used to provide five different model candidates for comparison with a 1263 Hz CF primary neuron. Pure-tone and speech-like stimuli originally presented to the neuron were presented to each of the five models. Selection of the best model was based on a qualitative evaluation of PIH shapes and a quantitative analysis of the number of peaks that matched between corresponding model and neuron vowel - Pulse Interval Histograms. (A vowel-PIH is a Pulse Interval Histogram constructed from the segment of responses corresponding to a single vowel in the stimulus.)

The best model was presented with several more pure-tone and speech-like stimuli previously presented to the neuron. Corresponding vowel-PIHs of the model and neuron generated from the responses to these stimuli were compared using a "fraction of misplaced peaks" metric. Using benchmark values obtained by comparing different neuron vowel-PIHs generated from responses to approximately the same intensity, it was determined that the model produced vowel-PIHs that fell within the benchmark for six or seven of the ten vowel sounds used.

In a future report the data presented in this report, especially the data on vowel-PIH shape presented in Section 8.7, will be used to supplement an analysis of the neuron and model POHs in order to modify the model to provide a better fit to the neural data.

Information generated from study of this and future versions of the model will be incorporated into the development of speech recognition systems based upon the performance characteristics of the auditory nervous system. Such systems would be a valuable tool to the Air Force in the fields of intelligence, communications and man-machine interface.

PREFACE

This is the final report on work performed under Contract F33615-75-C-5098, "Signal Processing in the Auditory Nervous System", University of Dayton Research Institute (UDRI), Dayton, Ohio; Dr. Duane G. Leet, Principal Investigator.

The entire program was conducted in support of Project No. 7232, "Application of Basic Biological Principles and Mechanisms to Operations and Design of Air Force Systems," Task 723202, "Physical and Physiological Mechanism Involved in the Reception of Acoustic Energy" administered by the Neurophysiology Branch of the 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. The period covered 1 March 1975 to 30 January 1976. Dr. Thomas J. Moore was the initiator and monitor of this research.

The author expresses his sincere appreciation to Dr. Moore for his invaluable assistance and suggestions, and to Dr. J. Ryland Mundie for his advice and encouragement throughout the project.

The contractor's report number is UDRI-TR-76.17.

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SECTION 1

BACKGROUND

Since early in 1960 the Aerospace Medical Research Laboratories has studied the information processing characteristics of the auditory system. In the period from 1965 to 1972, single unit studies of guinea pig primary auditory nerve were performed. A wide range of stimuli were used, including pure tones, speech, and synthetic speech-like sounds. Analysis of these data, collectively called the VIII Nerve Data Base, contributed to the development of an electronic analog model of the middle and inner ear called the ROC COC (Mundie et al., 1974). In a concurrent project, a neural model called the syncoder was developed and its behavior studied for a variety of stimuli (Mundie, 1969; Ziskin, 1971; Zellmer, 1972; Rock, 1973; Miller, 1974). These two projects have led to a partly qualitative, partly quantitative model of the primary auditory nerve (Mundie et al., 1974). This study extends these results by presenting a totally quantitative model and comparing PIHs computed from the model's responses to tone and speech-like stimuli to corresponding neuron PIHs.

SECTION 2

THE MODEL

The block diagram for the Primary Auditory Nerve Model is shown in Figure 1. Both the middle ear and analog cochlea components of the model are realized by an electronic analog device called the ROC COC Cochlear Filter, which was developed by James C. Rock. In this model, input voltage is equivalent to pressure at the tympanic membrane. The ROC COC's middle ear circuit is an active bandpass filter with the Bode magnitude function shown in Figure 2. The analog cochlea section of the ROC COC is a transmission line comprised of a cascade of lowpass filters whose schematic is shown in Figure 3. Note that each filter, or channel, is tapped to provide an output voltage analogous to the displacement at a point on the cochlea's basilar membrane. The effective magnitude Bode function from the ROC COC's input to a channel output is that of an asymmetrical bandpass filter, with the low frequency skirt having a 6 dB/octave slope and the high frequency skirt having a 100 dB/octave slope. The channel electronically closest to the ROC COC input, channel 1, corresponds to the basal end of the cochlea and has the highest peak frequency; the channel electronically furthest from the ROC COC input, channel 48, corresponds to the apical end of the cochlea and has the lowest peak frequency. Figure 4 shows the peak frequency and 6 dB down points for each of the 48 channels. It should be noted that each channel has been tuned to provide a maximum gain of one from ROC COC input to channel output.
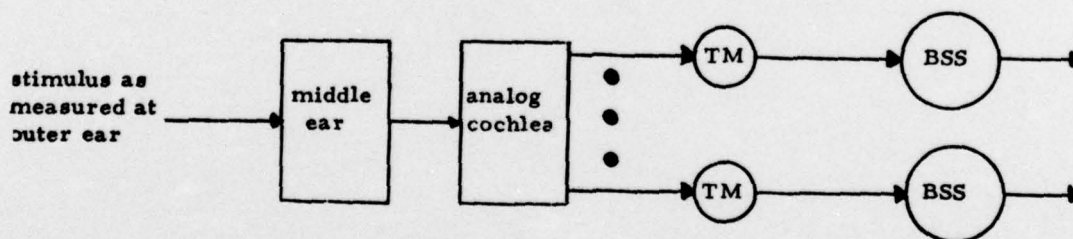
Figure 1. A Block Diagram of the Primary Auditory Nerve Model. The Middle Ear and Analog Cochlea Components are Realized by a Cochlear Filter. TM is the Transducer Module. BSS is the Basic Stochastic Syncoder.

As with the cochlea, a signal introduced at the ROC COC's input requires a significant amount of time to travel to any given channel, with the circuit components selected to approximate the times found in the cochlea (See Mundie et al., (1974) for details). Figure 5 shows this channel versus
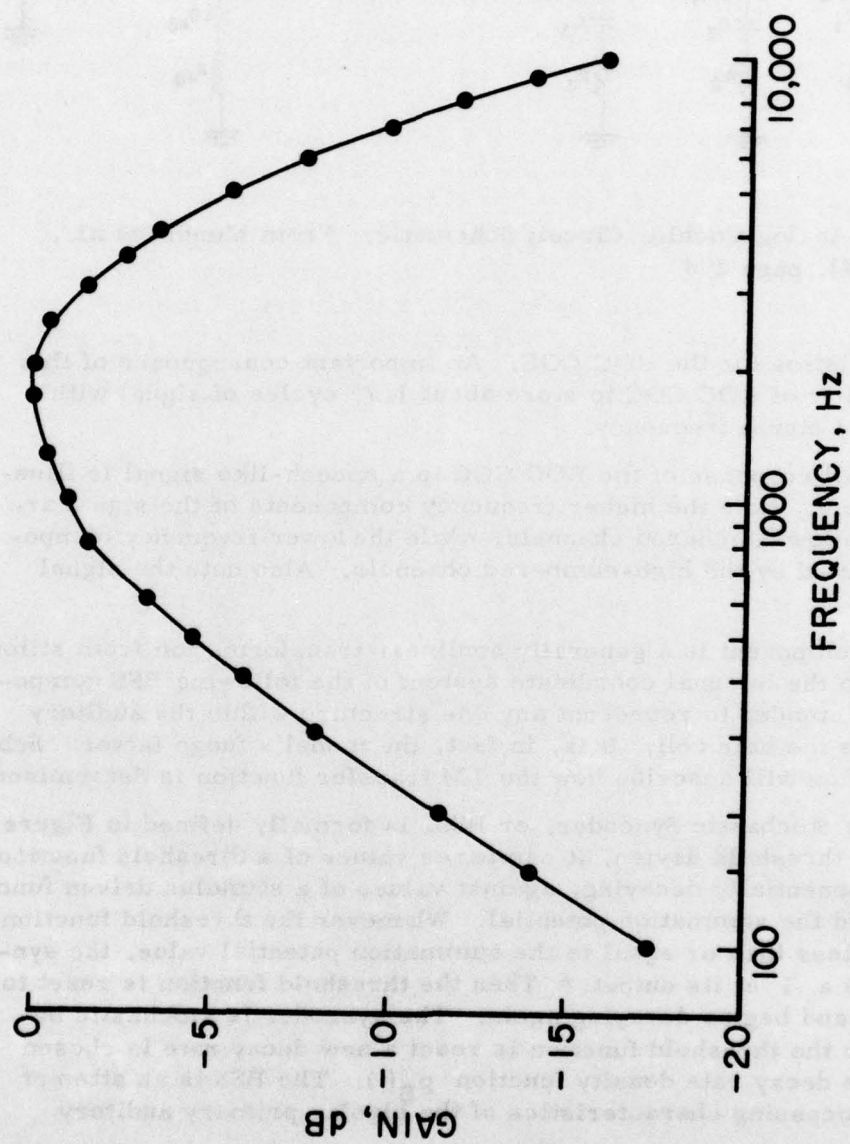
Figure 2. The Magnitude Transfer Function of the Middle Ear Circuit on the ROC COC Cochlear Filter.
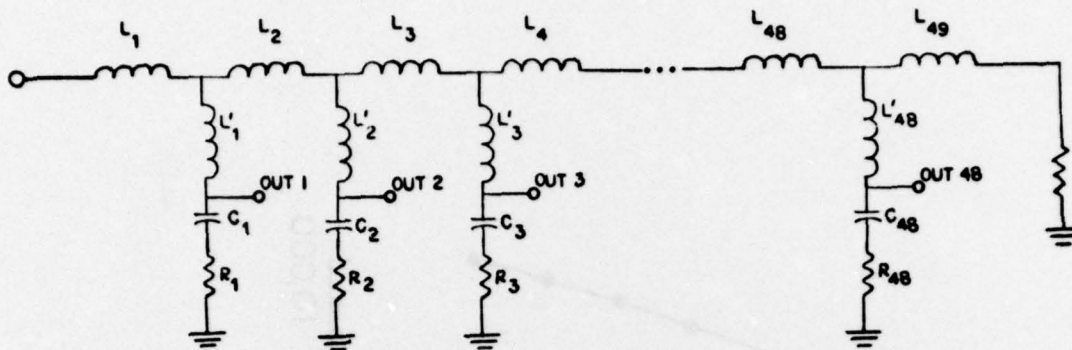
Figure 3. The Analog Cochlea Circuit Schematic. From Mundie et al., (1974), page 294

delay characteristics for the ROC COC. An important consequence of this delay is the ability of ROC COC to store about 1.75 cycles of signal within it, regardless of signal frequency.

The overall response of the ROC COC to a speech-like signal is illustrated in Figure 6. Note the higher frequency components of the signal are extracted by the low-numbered channels, while the lower frequency components are extracted by the high-numbered channels. Also note the signal delay.

The TM component is a generally nonlinear transformation from stimulus magnitude to the internal coordinate system of the following BSS component. It is not intended to represent any one structure within the auditory system, such as the hair cell. It is, in fact, the model's fudge factor. Subsequent discussion will describe how the TM transfer function is determined.

The Basic Stochastic Syncoder, or BSS, is formally defined in Figure 7. As a binary threshold device, it compares values of a threshold function, in this case exponentially decaying, against values of a stimulus driven function, here called the summation potential. Whenever the threshold function value becomes less than or equal to the summation potential value, the syncoder generates a 1 at its output. * Then the threshold function is reset to an initial value and begins decaying again. The syncoder is stochastic because each time the threshold function is reset a new decay rate is chosen according to the decay rate density function $p_B(.)$. The BSS is an attempt to model the processing characteristics of the bipolar primary auditory neuron.

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*This is not strictly true for the BSS. It has an absolute refractory period, ρ, after each pulse is generated, during which it can not generate another pulse regardless of the summation potential magnitude.
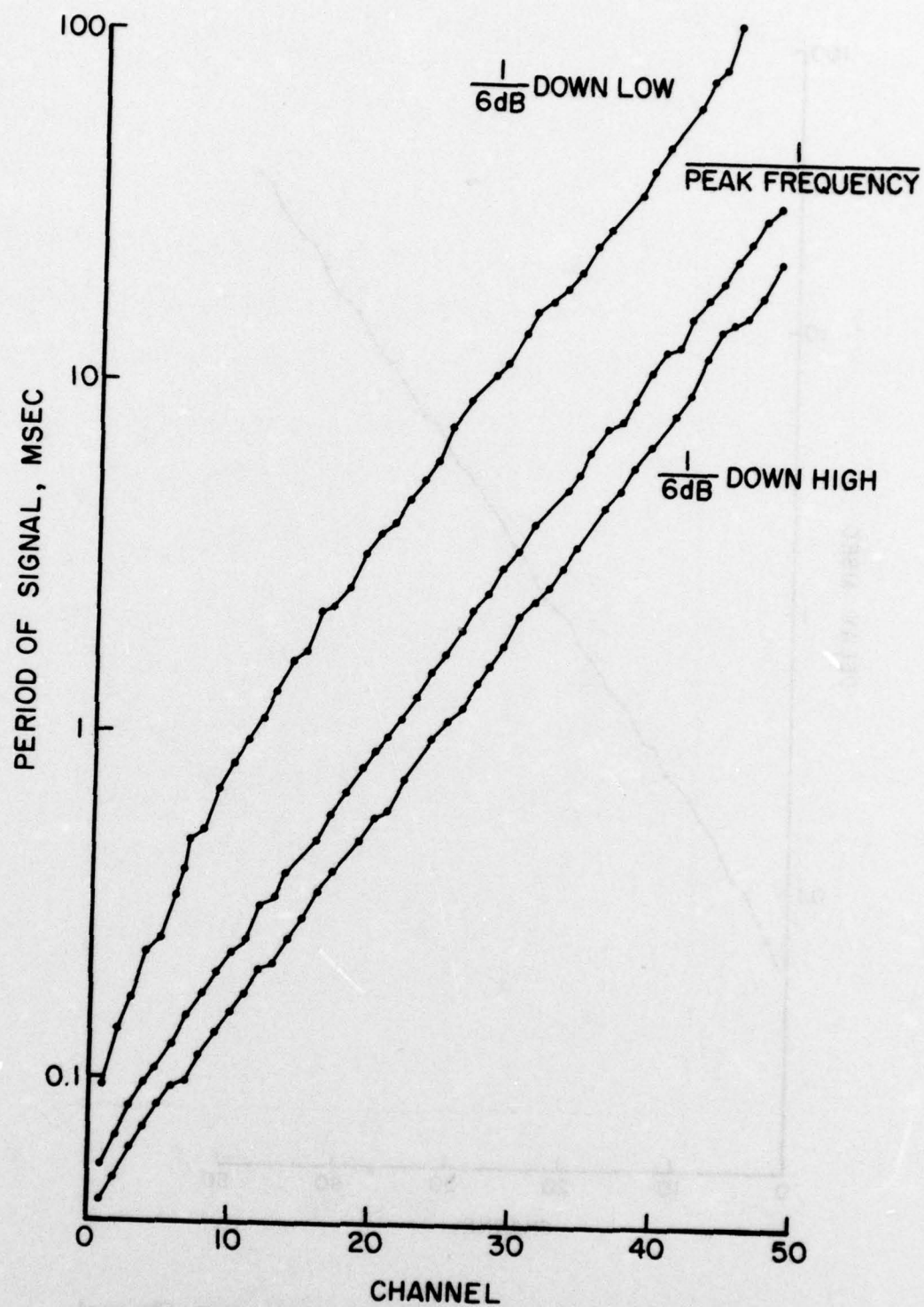
Figure 4. The ROC COC Pass-Bands.
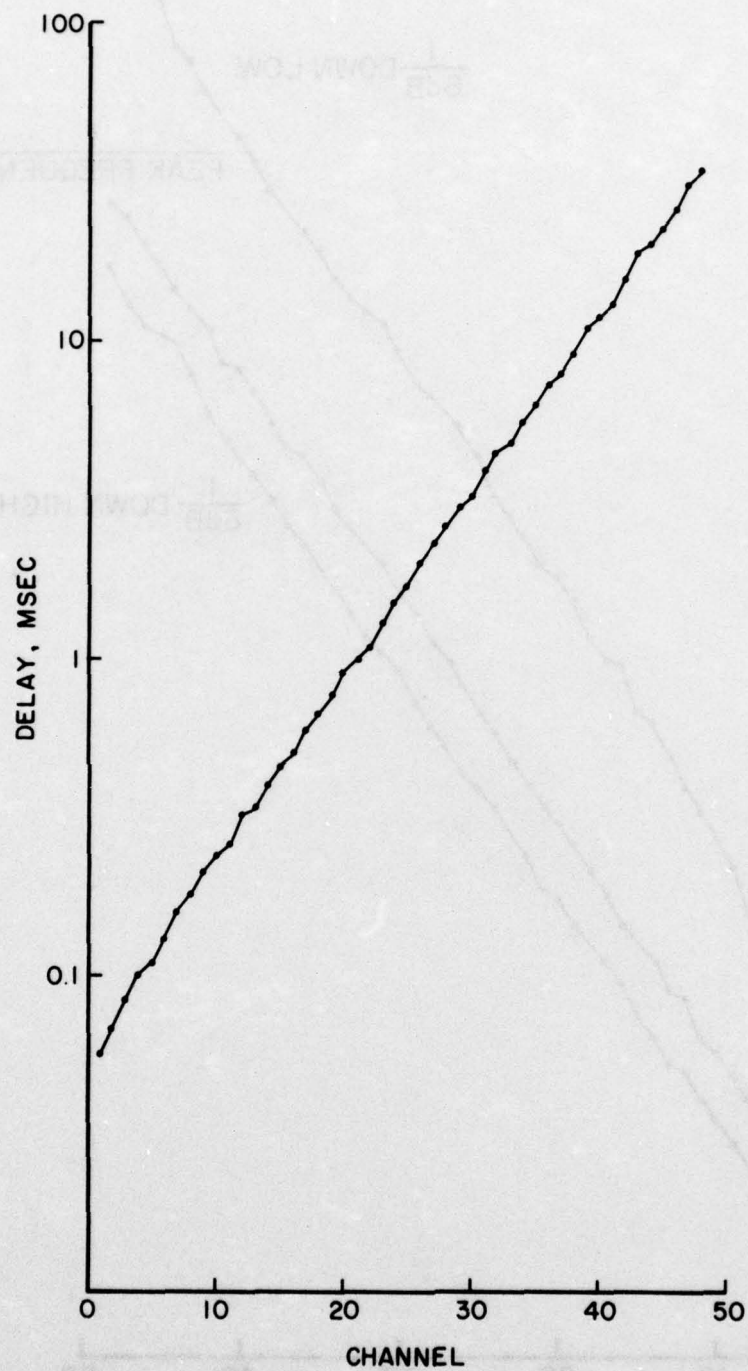
Figure 5. The ROC COC Signal Delay from Input to Channel.
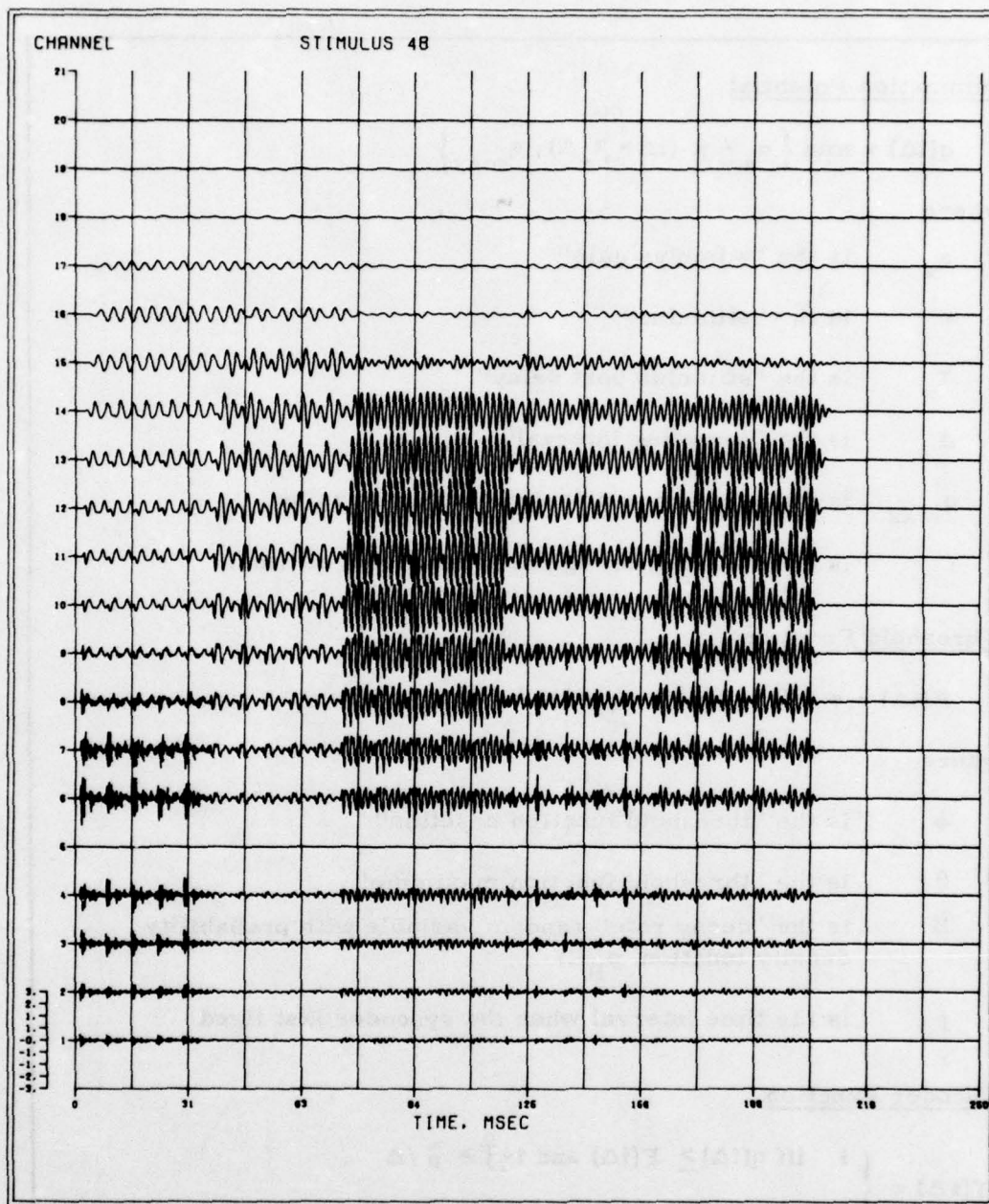
Figure 6. The Cochlear Surface Generated by the ROC COC Filter in Response to Stimulus 4B of the Glot-1 Stimulus Set. Channel 1 on this Plot Corresponds to Channel 2 of the ROC COC, Channel 2 Corresponds to ROC COC's Channel 4, Channel 3 Corresponds to ROC COC's Channel 6, and so on. Note that Channel 5 was not Functional.

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Summation Potential

$$q(i\Delta) = \min \left\{ a_x \cdot x(i\Delta - \tau_x \Delta), q_{max} \right\}$$

where

a_x is the "stimulus gain"

x is the "stimulus"

τ_x is the "stimulus port delay"

Δ is the "sampling interval"

q_{max} is the summation potential maximum value

i is an integer denoting the progression of time.

Threshold Function

$$F(i\Delta) = \phi + \theta \cdot \exp\left[B \cdot (j - i)\Delta\right]$$

where

ϕ is the "threshold function baseline"

θ is the "threshold function maximum"

B is the "decay rate" random variable with probability density function $p_B(.)$

j is the time interval when the syncoder last fired

Encoder Function

$$Y(i\Delta) = \begin{cases} 1 & \text{iff } q(i\Delta) \geq F(i\Delta) \text{ and } i-j > \rho/\Delta \\ 0 & \text{otherwise} \end{cases}$$

where

ρ is the "refractory period" (msec)

Figure 7. The Basic Stochastic Syncoder.

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SECTION 3

EXPERIMENTAL PROTOCOL

The actual model verification was preceeded by an intensive study of the behavioral characteristics of the BSS and related syncoders. Some pertinent results of this study are presented in Section 4. From this study procedures were developed for estimating the values of the model's parameters. These procedures are summarized in Section 5.

The verification procedure has been divided into four phases, with each phase examining the model's simulation capability in progressively greater detail. This report describes the results of the second phase.

In Phase 1, a model of a relatively high characteristic frequency (2700 Hz) neuron was developed that simulates the neuron's pure tone behavior. This phase provided a coarse verification of the model, since the frequency is high enough that the stimulus appears to the neuron or syncoder to be a step function rather than a pure tone. *

In Phase 2 a model was developed for a medium characteristic frequency neuron (1263 Hz). The development procedure was comprised of several iterations of the basic model development cycle: parameter value assignment, simulation, parameter value modification based on the results of previous simulations. A subset of the tonal and speech-like stimuli originally used on the neuron were presented to each iteration of the model. At the end of each development cycle, the model's PIHs were compared to those of the neuron using semi-quantitative metrics developed specifically for this purpose. New parameter values were selected based on all the previous iterations. After five cycles the best model was selected and the remaining stimuli originally presented to the neuron were presented to it. The PIHs of the neuron and the model were then compared.

Phase 2, which is presented in Sections 6 through 8, represents the next level of resolution in the verification procedure, since the frequency of a tonal stimulus is high enough to provide a good theoretical approximation to a step function and yet the PIH does have a periodic structure, with the period the same as the stimulus period. *

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*Section 4 provides the justification for this statement.

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SECTION 4

BEHAVIORAL CHARACTERISTICS OF A BASIC STOCHASTIC SYNCODER

4.1 RESPONSE TO A CONSTANT STIMULUS

It will be helpful to precede the discussion of the model's parameter estimation procedures with a description of the BSS's responses to some common stimuli.

Recall that the threshold function of a BSS is

$$F(i\Delta) = \phi + \theta \exp(B (j-i)\Delta)$$

If the stimulus is a constant, x, the summation potential will be a constant and the syncoder will fire whenever

$$\alpha_x \, x \geq \phi + \theta \exp(B (j-i)\Delta)$$

The greater-than relation is required because the discrete time domain is used. (Digitizing time introduces an error into all these calculations proportional to the sample interval.)

Assuming the equality holds for development purposes, the interpulse intervals will be given by

$$i\Delta = - \frac{1}{B} \ln (\frac{\alpha_x \, x - \phi}{\theta})$$

The density function of interpulse intervals, $p_I(.)$, which is just the normalized PIH constructed from the responses of the BSS to a number of presentations of the stimulus, can be obtained from the decay rate density function through the transformation

$$p_I(i\Delta) \simeq p_B(- \frac{1}{B} \ln (\frac{\alpha_x \, x - \phi}{\theta}))$$

Again, the approximation sign must be introduced because time is discrete here. Note that it is also possible to obtain $p_B(.)$ from $p_I(.)$. Figure 8 is an example of the POH and PIH constructed from the responses of a BSS to a constant stimulus.

4.2 RESPONSE TO A STEP STIMULUS

The standard step stimulus is sketched in Figure 9. Referring to this figure, the behavior has been partioned into the following five time periods:
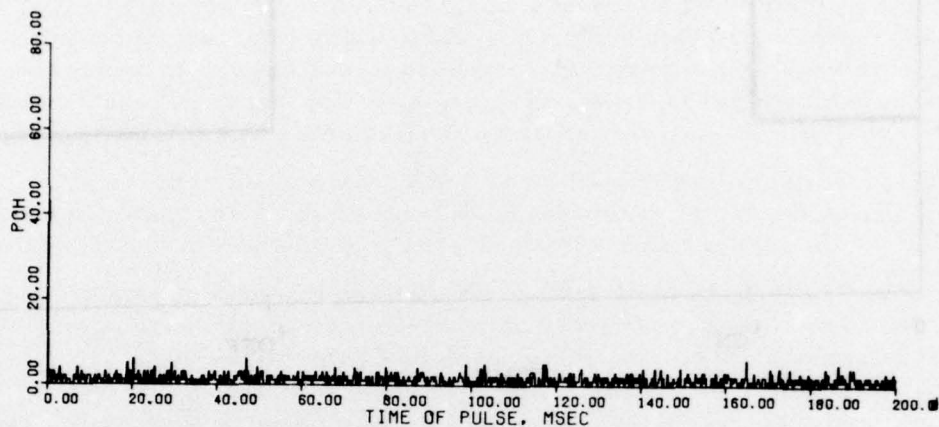
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FIGURE   POH FOR BASSETT.J . 03/31/76.3. 1.
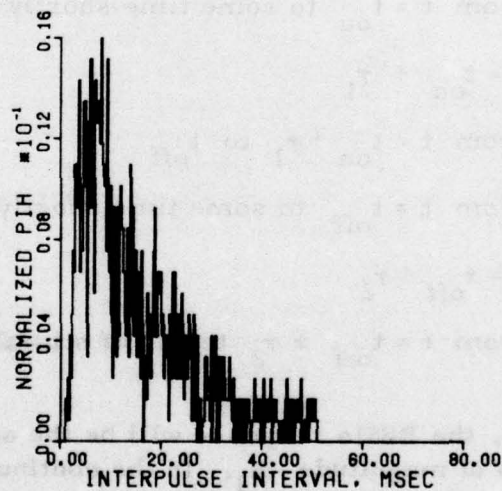
FIGURE   BASSETT.J . 03/31/76.3. 1.
DEFINING INTERVALS 1 TO 999
AVERAGE = 15.59   NUMBER OF INTERVALS = 1176

Figure 8.   The POH and the PIH Constructed from the Responses of a
BSS to 100 Presentations of a Constant Stimulus.   The BSS
had a Threshold Function $F(i\Delta) = 271.23 \exp (B(j-i)\Delta)$.
The Stimulus Magnitude was 60.46.   The Density Function
$p_B(.)$ is that of Model 03/31/76.3 in Figure 13.

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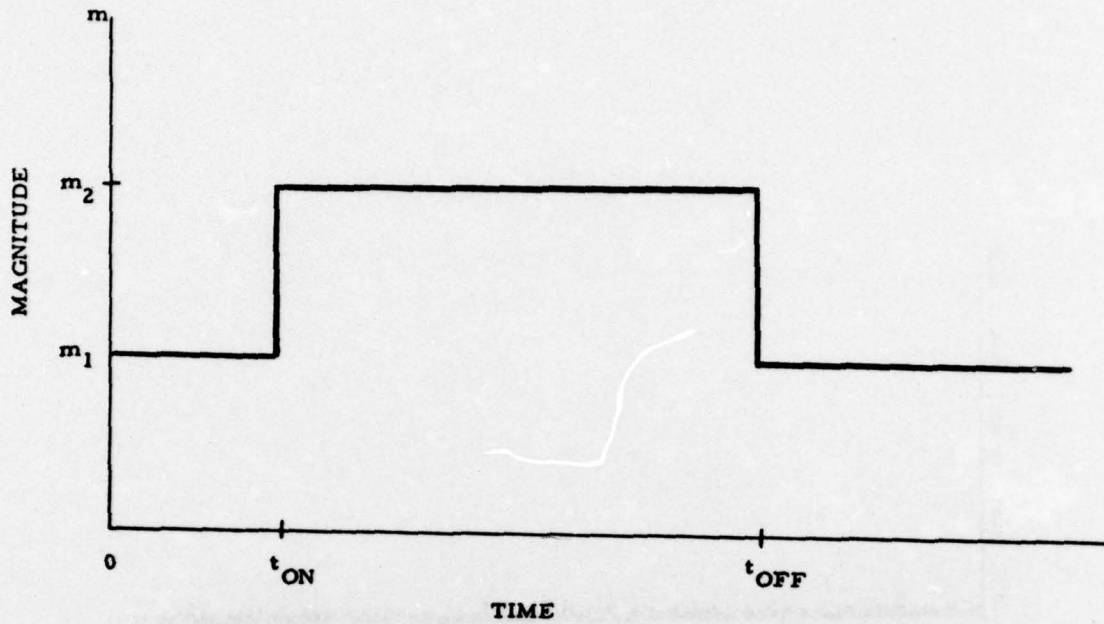
Figure 9. The Step Stimulus.

T_1 is from $t = 0$ to $t = t_{on}$

T_2 is from $t = t_{on}$ to some time shortly thereafter,

$t = t_{on} + \tau_1$

T_3 is from $t = t_{on} + \tau_1$ to t_{off}

T_4 is from $t = t_{off}$ to some time shortly thereafter,

$t = t_{off} + \tau_2$

T_5 is from $t = t_{off} + \tau_2$ to end of stimulus presentation.

In regions T_1 and T_5, the BSS's response will be the same as its response to a constant stimulus of magnitude m_1. In the continuous time domain, the normalized PIH will be

$$p_I(t) = p_B\left(- \frac{1}{B} \ln \frac{\alpha_x m_1 - \phi}{\theta}\right)$$

Again, if time is discrete, the probability will be given only at integer multiples of the same interval, and it will be only an approximation, with error proportional to the sample interval.

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The BSS's behavior in region T_3 will also be that of a constant stimulus, this time with magnitude m_2. The continuous time domain PIH will be

$$p_I(t) = p_B(-\frac{1}{B}\ \ln\frac{\alpha_x\ m_2 - \phi}{\theta})$$

The average interpulse interval in region T_3 will be less than the average interpulse interval in regions T_1 and T_5.

The behavior in regions T_2 and T_4 are not easily described quantitatively. Qualitatively, a large peak of activity will occur at $t = t_{on}$. If this peak is large enough, the activity immediately after t_{on}, as seen in the POH, will be suppressed. In both cases the height of the peak and the length of the suppression will be directly proportional to the difference between m_2 and m_1.

An example of the POH and PIH computed from the responses of a BSS to 100 presentations of a step stimulus is shown in Figure 10.

If the stimulus has a finite slope at t_{on} and t_{off}, giving it a trapezoidal shape, the BSS's behavior in regions T_2 and T_4 will be modified somewhat: the peak in the POH at t_{on} will not be as sharp, and the suppression of activity will not be as strong. Section 7 contains an example of an intensity series based on trapezoidal stimuli.

4.3 RESPONSE TO A SINUSOIDAL STIMULUS

If the stimulus to a BSS is a sinusoid, the summation potential will also be a sinusoid of the same frequency, say $A\sin\omega t$. Suppose the syncoder has fired during the sample interval j. The syncoder's threshold function will reset at that time and begin decaying again with a decay rate B_j selected according to the decay rate density function $p_B(.)$. The first time $i\Delta$ the stochastic syncoder can fire is when the threshold function has decayed to A. Furthermore, the syncoder must fire within one period $T = 2\pi/\omega$ of $i\Delta$, since the sinusoid will have a value A sometime during that period, and the threshold function is a monotonically decreasing function. As a matter of fact, at the most the threshold function will have decayed to a value

$$\theta\ \exp((i-j)\Delta B_j)\cdot(1-\exp(-2\pi\ B_j/\omega))$$

below that at $i\Delta$.

If the frequency of the sinusoid is high enough, the normalized PIH constructed from the responses of the stochastic syncoder will have an envelope that is approximately the same shape as that constructed from the responses of the syncoder to a step of the same magnitude. Within this envelope, the PIH will be periodic, with a period equal to that of the sinusoid. There are

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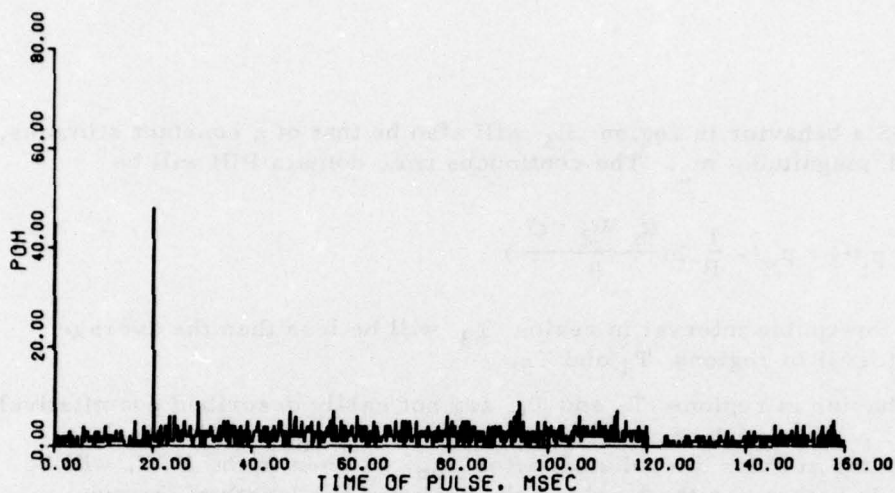
FIGURE   POH FOR LEET. 0   . 03/31/76.6. 2.
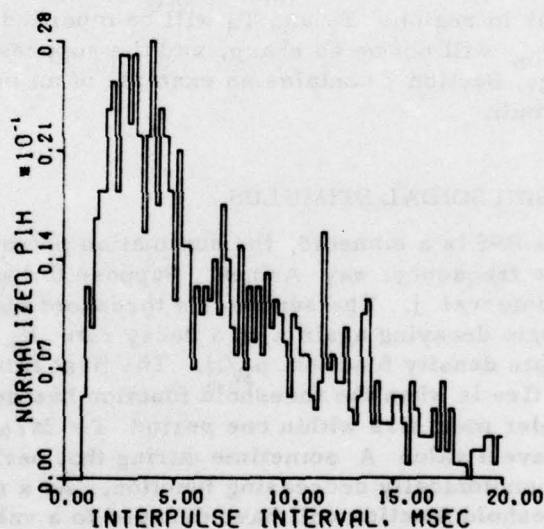
FIGURE   LEET. 0   . 03/31/76.6. 2.
DEFINING INTERVALS 100 TO 600
AVERAGE = 7.90 NUMBER OF INTERVALS = 1149

Figure 10.   The POH and Normalized PIH of a BSS: 100 Presentations of
a Step Stimulus Beginning at 20 msec and Ending at 120 msec.
The Average Interpulse Interval is 12.0 msec on 1169 Pulses.

two nonquantitative qualifiers in this statement: "high enough" and "approximately the same shape as". The function

$$\frac{.01}{A} e^{\frac{2\pi}{\omega} B_m} ,$$

where B_m is the maximum decay rate possible for the syncoder, can be used as a measure of the difference between the shape of the envelope of the sinusoid's normalized PIH and the shape of the normalized PIH of a step with the same magnitude.

Figure 11 is the POH and normalized PIH computed from the responses of a BSS to a 1 kHz sinusoid beginning at 20 msec and ending at 120 msec. Note that both histograms have an envelope shape similar to that generated by a step stimulus. The interval between the peaks in both histograms is 1 msec, the period of the stimulus.

SECTION 5

MODEL PARAMETER ESTIMATION

5.1 INTRODUCTION

There are multiple sources of error associated with any procedure developed for estimating the parameter values of any neural model. A list that does not exhaust the possibilities is

(1) sampling error
(2) measurement error in the data acquisition system
(3) drifting system parameters
(4) neuron to neuron variation in parameters
(5) preparation to preparation variation in parameters.

In addition, the available neurophysiological data places restrictions on the nature of the parameter value estimation procedures. For instance, the only system measurements permitted are at the input to the middle ear and at the output of the primary auditory neuron. Furthermore, all stimuli must be time varying; constant stimuli, which are convenient for determining the BSS's parameter values, are not permitted.

The following subsections detail practical procedures for estimating the model's parameter values, procedures that attempt to minimize the estimation error and yet conform to the restrictions placed on them by the neurophysiological data. The next section applies these procedures to the data from a particular neuron.

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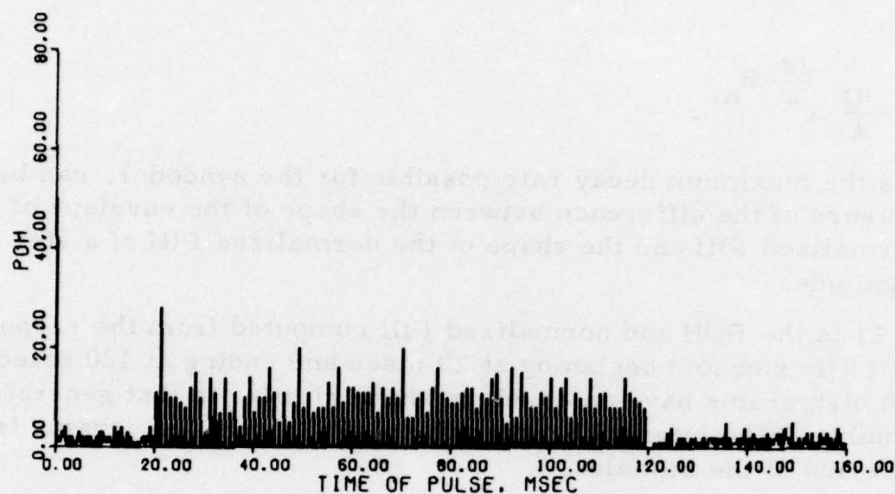
FIGURE   POH FOR LEET. 0   . 03/31/76.6. 1.
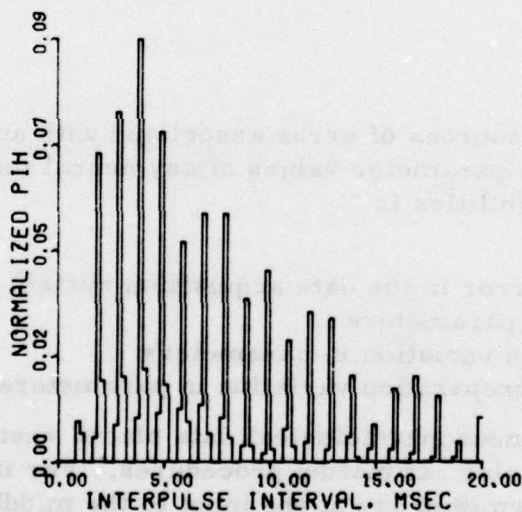
FIGURE   LEET. 0   . 03/31/76.6. 1.
DEFINING INTERVALS 100 TO 600
AVERAGE = 7.99 NUMBER OF INTERVALS = 1114

Figure 11.   The POH and Normalized PIH Computed from the BSS's
Responses to 100 Presentations of a 1 kHz Sinusoid.

5.2 BSS PARAMETER ESTIMATION

The procedure for estimating the parameter values of the BSS when it is embedded in the environment of primary auditory nerve is summarized in Procedure A. Referring to Figure 7, the parameter values and functions to be estimated are ϕ, α_x, τ_x, β, ρ, and $p_B(.)$. All but $p_B(.)$ and θ can be assigned values without resorting to further measurement: ϕ and α_x can be assigned values of zero and one respectively, since their true values can be absorbed into the TM transfer function: τ_x is assigned a value of zero because it is not of immediate interest: ρ is assigned a value of 1 msec.

To justify the technique in Procedure A for estimating θ, consider the continuous time argument first. If a constant stimulus x_1 is presented to an isolated BSS, the PIH constructed from the responses will be a projection of the domain of $p_B(.)$ into the time dimension using the transformation

$$t = -\frac{1}{B} \ln \frac{x_1}{\theta} .$$

A second constant stimulus x_2, different from x_1, will produce a second transformation

$$t = -\frac{1}{B} \ln \frac{x_2}{\theta} .$$

For the particular case of $B = B_{avg}$, the average decay rate, the times can be measured experimentally as the average interpulse intervals t_1 and t_2 respectively, giving the following two equations:

$$t_1 = -\frac{1}{B_{avg}} \ln \frac{x_1}{\theta}$$

$$t_2 = -\frac{1}{B_{avg}} \ln \frac{x_2}{\theta}$$

The function $\theta e^{-B_{avg}t}$ can be approximated by the function $\frac{1}{t}$ over some interval of t that depends on B. * $x = \frac{1}{t}$ will be used here and correction for error will be made in the TM transformation.

---

*The approximation turns out to be quite a good one for the values of B_{avg} *that have been determined from the experimental data.* For instance, for a neuron with $f(t) = 232 \exp(-0.081 \cdot t)$ the percent was no greater than $5 \times 10^{-3}\%$ in the operating range of the neuron.

PROCEDURE A
BSS PARAMETER ESTIMATION IN
AN AUDITORY SYSTEM ENVIRONMENT

0. **ASSUMPTIONS:**

   a. $\phi = 0$

   b. $\alpha_x = 1$

   c. $\tau_x = 0$

   d. $\rho = 1$ msec.

   e. The PIH of a primary auditory nerve's spontaneous activity
      is known. The average interpulse interval for this PIH is
      t_s.

1. **DETERMINE** θ

   Obtain the average interpulse interval t_m from the PIH of the
   primary auditory nerve's response to a high frequency pure
   tone. The higher the frequency the better the estimate.
   Compute:

   (A. 1)
   $$B_{avg} = \frac{\ln(t_s/t_m)}{t_s - t_m}$$

   (A. 2)
   $$\theta = t_s^{-1} \exp(B_{avg} \cdot t_s)$$

2. **DETERMINE** $p_B(.)$

   Normalize the spontaneous activity PIH to create the density
   function $p_s(.)$, whose domain is time. Compute:

   (A. 3)
   $$p_B(B) = p_s \left(-\frac{1}{i\Delta} \ln \frac{1}{t_s\theta} \right)$$

Forcing $x_1 = 1/t_1$ and $x_2 = 1/t_2$ and solving for B_{avg} and θ:

$$B_{avg} = \frac{\ln(t_1/t_2)}{t_1 - t_2}$$

$$\theta = \frac{1}{t_1} \exp(B_{avg} \cdot t_1) \ .$$

Making time discrete complicates the argument by introducing an error into the estimates of t_1 and t_2 proportional to the width of the sample interval. For the case where the BSS is in the primary auditory nerve environment additional error is introduced, since a high frequency sinusoid must be substituted for one of the constant stimuli. (The spontaneous activity can be used for the other stimulus.) The error will be proportional to the sinusoid's period.

The technique in Procedure A for estimating the decay rate density function follows directly from the fact that in the model spontaneous activity is generated by having the TM generate a constant output when it has no input. As demonstrated previously, the PIH constructed from the responses of the BSS to a constant stimulus has the same shape as $p_B(.)$. It is only necessary to transform the time domain to the decay rate domain using A.3.

5.3 TRANSDUCER MODULE TRANSFER FUNCTION ESTIMATION

The purpose of the Transducer Module, or TM, is to transform the coordinate system of the stimulus space as seen at the middle ear into the coordinate system used by the BSS following the TM. The stimulus space at the middle ear is two dimensional. One dimension is stimulus pressure, measured in units of dB attenuation from 100 dB SPL; the other is time. The response space of the TM is one dimensional, with units of $\sec^{-1}$.

Procedure B outlines the procedure for obtaining the TM transfer function. Step 2 is necessary to correct for the $1/t$ approximation made in estimating the θ parameter value. This step estimates the transfer function for rarefaction. Step 3 is an attempt to estimate the transfer function for condensation, since such values are not available from neurophysiological data.

Figure 15 is a complete estimate constructed using this procedure. Note that the condensation side of the abscissa in the figure is a reflection of the rarefaction side. The y axis is the locus for the spontaneous activity.

<div style="border:2px solid black; padding:1em">

PROCEDURE B

ESTIMATION OF TRANSDUCER MODULE TRANSFORMATION

1. Obtain an intensity series on the primary auditory neuron.

2. Plot stimulus intensity in dB attenuation from 100 dB SPL (domain) against $\theta \cdot \exp(-B_{avg} \cdot t_{avg})$, where t_{avg} is the average interpulse interval for each stimulus magnitude used.

3. Reflect the above curve, which is the positive portion of the transfer function, across the ordinate and then across the line parallel to the abscissa and through the range value associated with spontaneous activity.

</div>

SECTION 6

A MODEL OF A MEDIUM CF NEURON

6.1 FIVE ALTERNATIVE MODELS

Phase 2 of the verification procedure requires the development of a model for a neuron with a characteristic frequency of around 1 kHz. This frequency optimizes the criterion that it be high enough to introduce little error into the TM estimation procedure, Procedure B, and yet low enough to provide structure to the PIHs. A search was made of the VIII Nerve Data Base for a neuron satisfying these requirements:

(1) The neuron has a CF of around 1 kHz.
(2) An intensity series exists.
(3) Responses to speech or speech-like stimuli exist.
(4) There is a run of spontaneous activity.
(5) The neuron is a displacement following neuron.

This last requirement was imposed because it was found in some preliminary experiments that some neurons do not follow basilar membrane displacement as predicted by the Cochlear Filter. Instead, they seem to follow the membrane's velocity. It was decided to avoid this added complication during the first two phases of the model's verification.

Unfortunately, a neuron with all of the above requirements could not be found. The best data available, and the neuron selected for model development, 710827/11, * lacked a spontaneous activity record and some important values in the intensity series. To circumvent the lack of a spontaneous activity record, the brief periods of spontaneous activity following the responses to the pure tones were added together to give the approximate PIH shown in Figure 12.

Five different models were developed from four different attempts to approximate the neuron's true spontaneous PIH with several points and a linear interpolation between the points. In Figure 13, the four approximations are juxtaposed with the curve of Figure 12. For each model, the several selected points were supplied to the computer program TDENFCN, ** which used Procedure A to generate a $p_B(.)$ and one of the sets of syncoder parameters listed in Table 1. Threshold functions for each of the five models, computed using the average decay rate, are plotted for comparison in Figure 14. Figure 15 shows the TM transfer functions for the models which were computed using Procedure B.

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*The neuron was recorded on August 27, 1971, and was the eleventh neuron recorded that day.
**A user's manual for each of the programs used in the simulation effort is included in (Leet, 1976) as the Appendix.
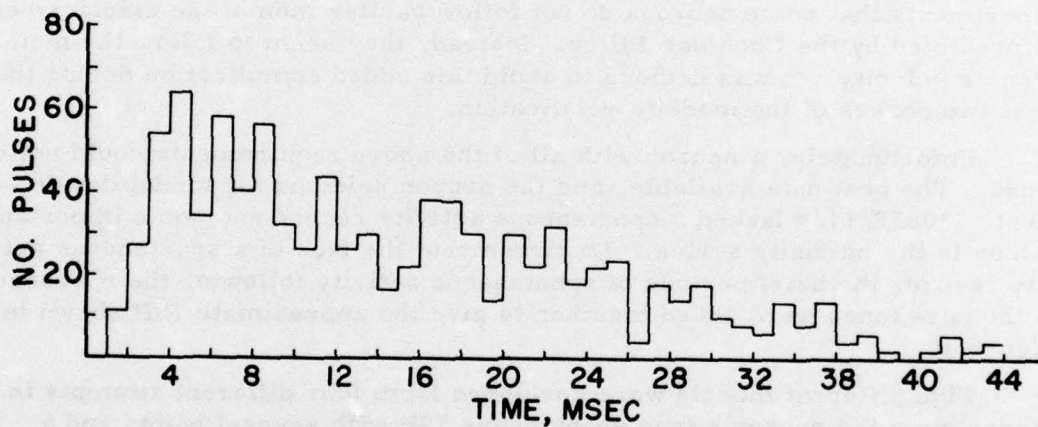
Figure 12. Pulse Interval Histogram Constructed by Summing the
Pulse Interval Histograms Created from the 130 to 200
msec Segment of the Responses of Runs 18 through 24
of Experiment 710827/11. The Sample Intervals are
1 msec.
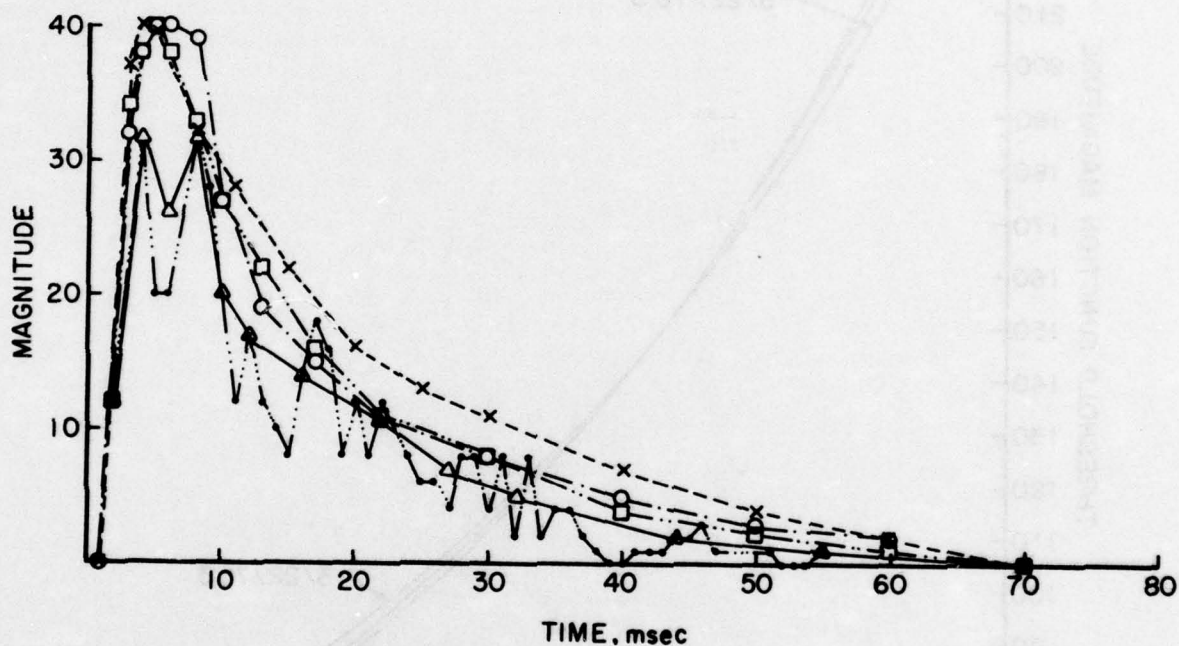
Figure 13. Four Attempts to Fit the Approximate PIH of Figure 6. 1.
The Ordinate is an Arbitrary Unitless Scale.

·—— ··· ——·	The Approximate Spontaneous PIH Shown in Figure 12.
o—— · —— · o	Model 03/20/76. 3.
x - - - - - - - - - - x	Model 03/22/76. 3.
□ ·· —— ·· —— □	Models 03/24/76. 3 and 03/24/76. 5.
Δ ——————— Δ	Model 03/31/76. 3.

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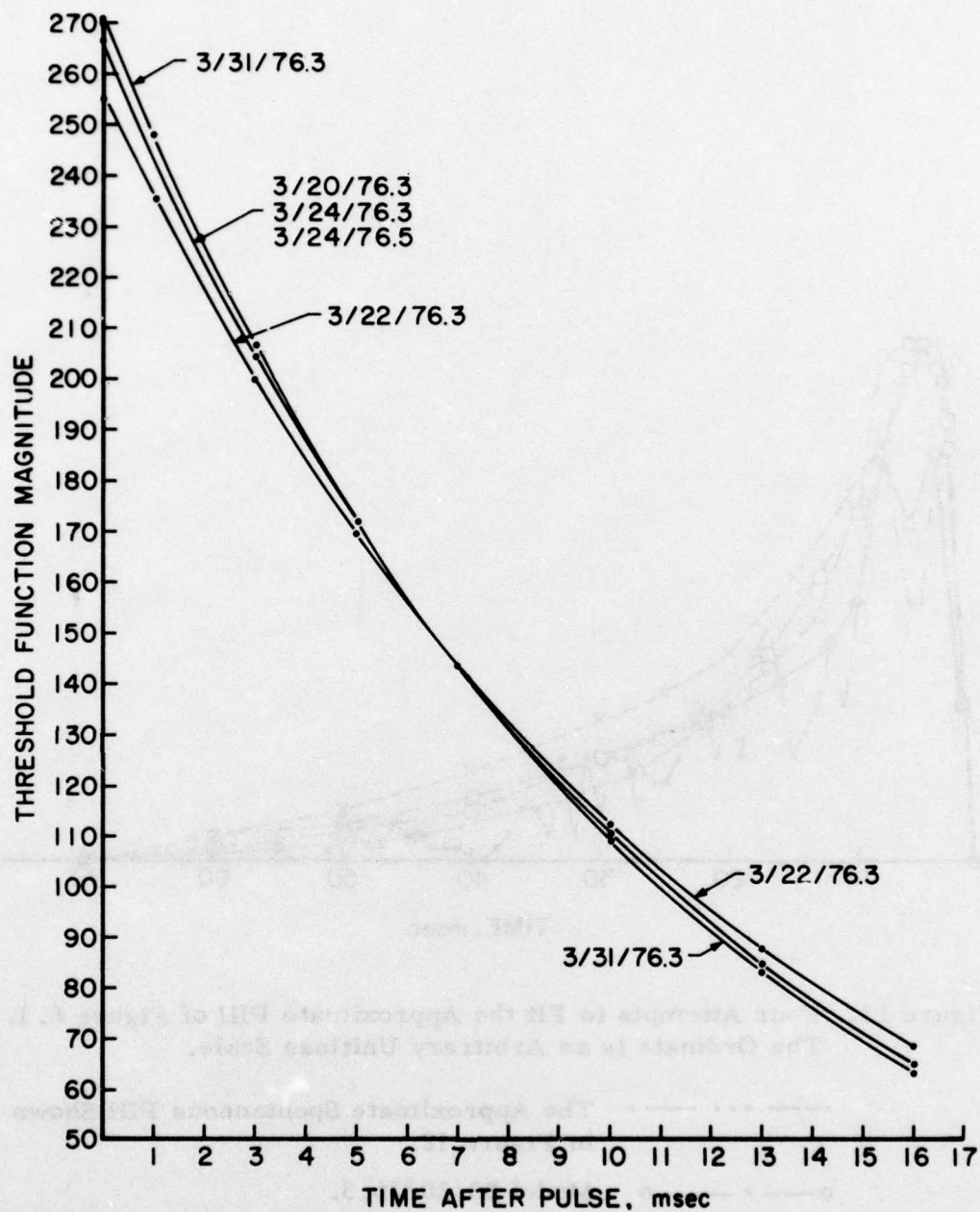
Figure 14. Threshold Functions for the Five Models of the Medium CF Neuron 710827/11. These were Constructed Using the Average Decay Rate, B_{avg}, and θ Values Listed in Table 1.

dB attn	3/24/76. 3 3/20/76. 3	3/22/76. 3	3/24/76. 5	3/31/76. 3
100	57. 24	51. 21	58. 15	60. 46
63	84. 87	87. 78	84. 46	83. 38
55	131. 9	132. 6	131. 8	132. 5
50	145. 1	145. 1	145. 1	145. 1
45	138. 0	138. 5	138. 0	137. 8
40	131. 4	132. 2	131. 3	130. 9
35	138. 2	138. 6	138. 1	137. 9
30	140. 8	141. 1	140. 8	140. 7
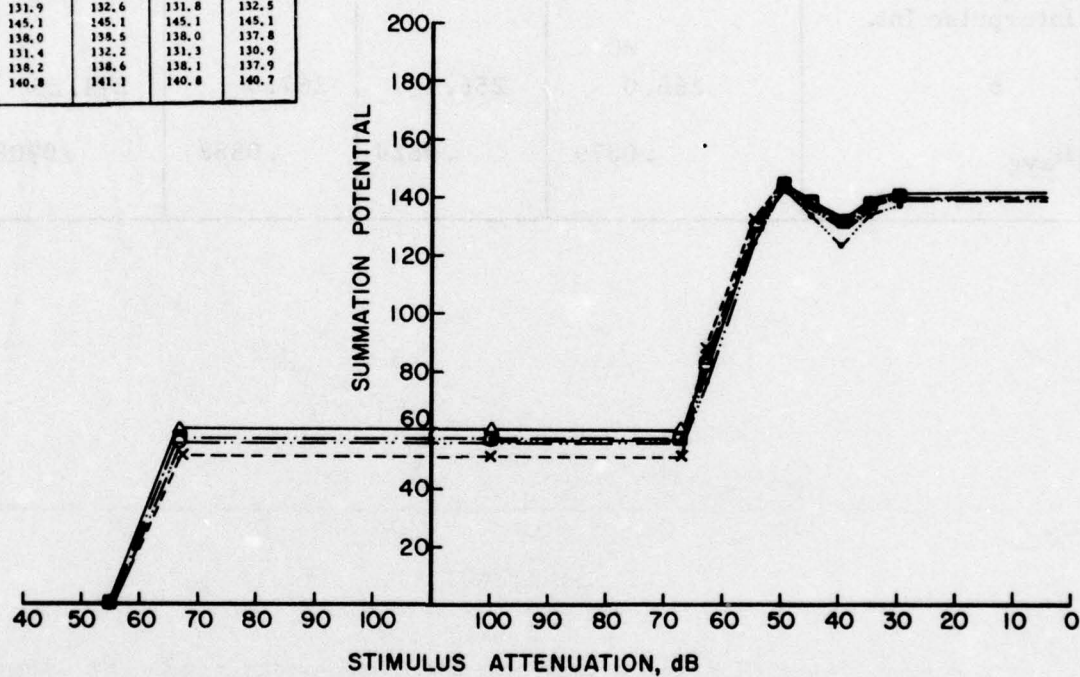
Figure 15.   The TM Transfer Functions for the Five Models of the Medium CF Neuron 710827/11.   The Symbol Key is the Same as Figure 13.

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TABLE 1

BSS PARAMETERS FOR THE FIVE MODELS
OF A MEDIUM CF NEURON 710827/11

	3/20/76.3	3/22/76.3	3/24/76.3	3/31/76.3
Low Avg. Interpulse Int.	6.89	6.89	6.89	6.89
High Avg. Interpulse Int.	17.47	19.53	17.20	16.54
θ	266.0	256.1	267.5	271.23
B_{avg}	.0879	.0824	.0888	.0908

6.2   THE BEHAVIOR OF THE MODELS

A total of 24 runs were recorded on neuron 710827/11, including an intensity series of 63, 60, 55, 50, 45, 40, 35, and 30 dB attenuation and a number of runs where the neuron was responding to stimuli from the Glot-1 Stimulus Set. The two magnitudes of the 1263 Hz tone stimulus that produced the smallest and largest average interpulse intervals in the neuron's intensity series, 63 and 50 dB attenuation, and a representative Glot-1 stimulus, 3B at a magnitude of 10 dB attenuation, were chosen as the stimulus subset used to select the best model from the five candidates.

The pure tones were presented to the neuron and the models in a 10-90-10 trapezoidal envelope: zero for a short period of time, rising linearly to full magnitude in 10 msec, remaining at full magnitude for 90 msec, decaying linearly back to zero magnitude in 10 msec, and remaining at zero after that. For the model, the pure tones were generated by the MAKSTIM program. This program also generated the TM responses.

The BSS simulations were performed by the BSSSIM program. The SIMHIS7 program was used to generate the POHs and PIHs from the responses produced by BSSSIM. The SIMHIS6 program was used to generate the corresponding POHs and PIHs from the neural data.

Figures 16 and 17 present the POHs computed from the responses of two of the models to the tones juxtaposed with the corresponding neuron POHs. Two differences between the models' and the neuron's POHs are evident. The explanations for these differences reveal the impact digitization will have on the interpretation of the model's behavior. The first difference is that the peaks in the model POH's are much sharper during the tone. The proposed explanation for this is that the neuron computes on an analog signal, and this signal and/or the neuron's threshold function contains a small amount of noise; enough noise to cause a ± 1 time bin error in the time of pulse occurrence from stimulus presentation to stimulus presentation. It is expected that, at least during the first two phases of the model's verification, the error introduced into the analyses by ignoring this noise will be insignificant.

The second difference between the models' and the neuron's POHs is that the models' POHs are modulated, with the low points in the activity being 19.6 msec apart. This is caused by a peculiar relationship between the frequency of the stimulus, the sampling rate, and the transfer characteristics of the Transducer Module. Figure 18 demonstrates this relationship. In Figure 18(a), the 1263 Hz sinusoid is sampled in such a way that one of the sampled values (bars) occurs just at its positive peak. The TM transforms these sample interval values as shown in column (a) of Figure 18(c). Note that there is one relatively large magnitude in the cycle. In Figure 18(b), on the other hand, the sampling is performed one-quarter cycle later. Such a situation will occur 19.6 msec after the previous one. The TM transforms the sample values marked by the bars in this figure to the sample values shown in column (b) of Figure 18(c). There is no large magnitude in this cycle. In fact, the activity of the syncoder will be at the spontaneous level.

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Figure 16. Pulse Occurrence Histograms Computed from the
Responses to 100 Presentations of a 63 dB Attenuation,
1263 Hz Pure Tone Presented in a 10-90-10 Trapezoidal
Envelope.

(a) Neuron 710827/11, Run 24.

(b) Model 03/20/76. 3.

(c) Model 03/31/76. 3.
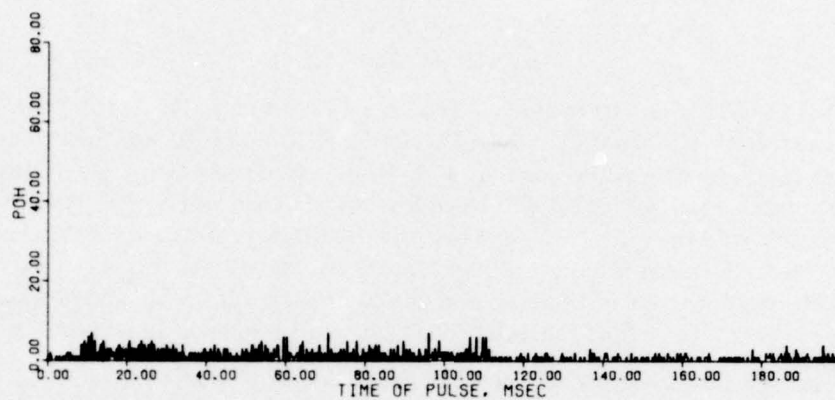
FIGURE   POH FOR 710827   . 11.. 24.

(a)
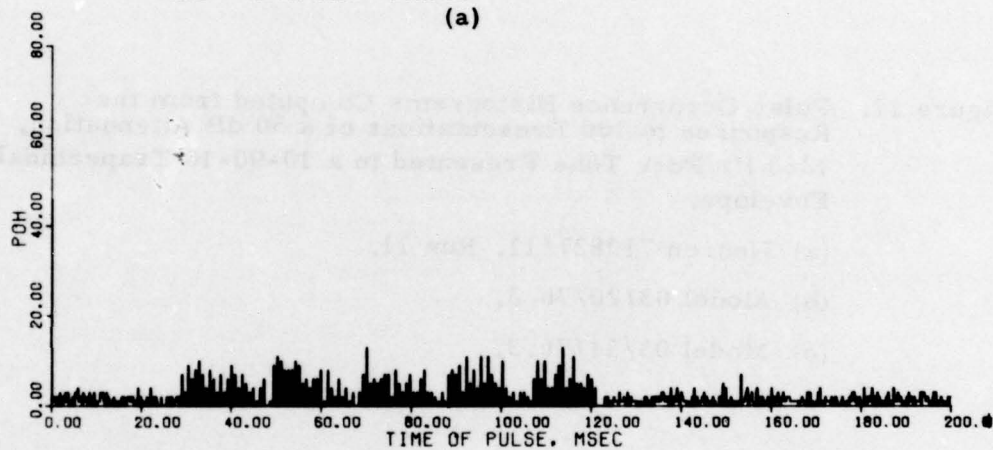
FIGURE   POH FOR BASSETT.J . 03/20/76.3. 2.

(b)
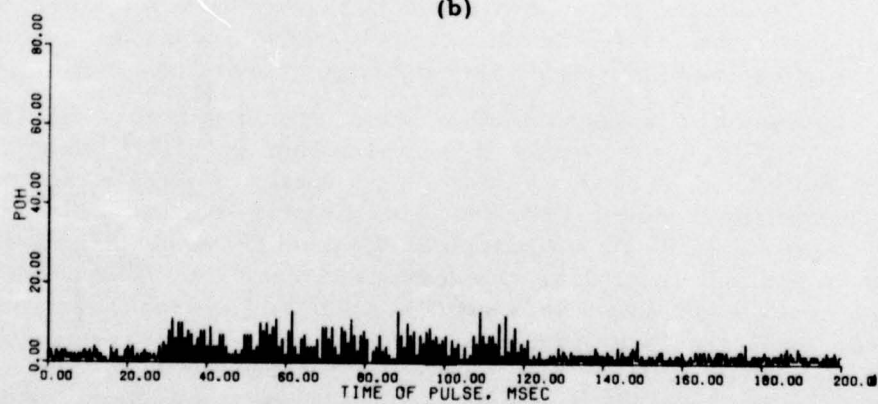
FIGURE   POH FOR BASSETT.J . 03/31/76.3. 2.

(c)

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Figure 17.   Pulse Occurrence Histograms Computed from the Responses to 100 Presentations of a 50 dB Attenuation, 1263 Hz Pure Tone Presented in a 10-90-10 Trapezoidal Envelope.

(a) Neuron 710827/11, Run 11.

(b) Model 03/20/76.3.

(c) Model 03/31/76.3.

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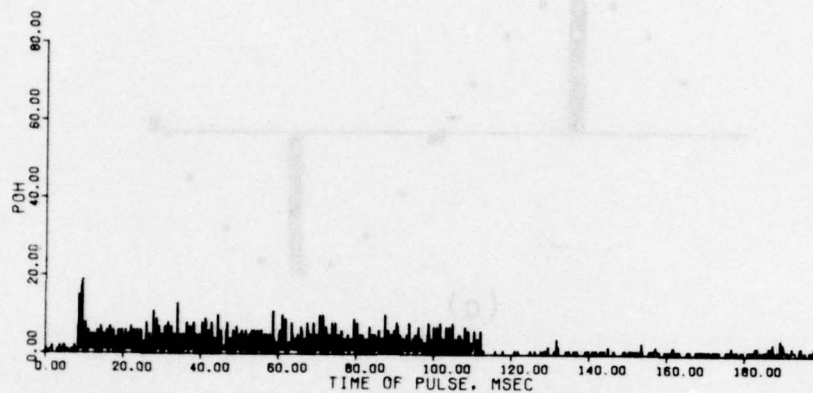
FIGURE   POH FOR 710827   . 11., 18.

(a)
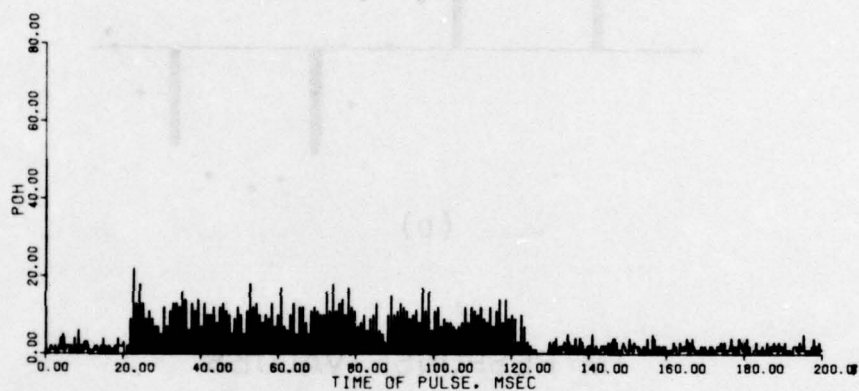
FIGURE   POH FOR BASSETT.J . 03/31/76.3. 3.

(b)
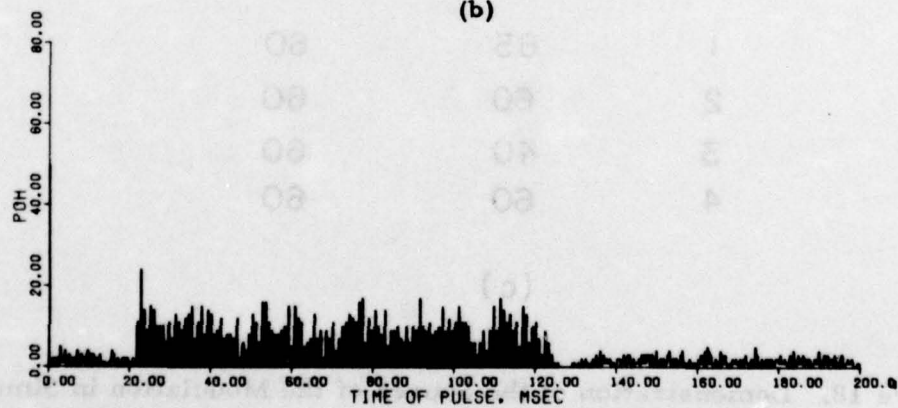
FIGURE   POH FOR BASSETT.J . 03/20/76.3. 3.

(c)

45
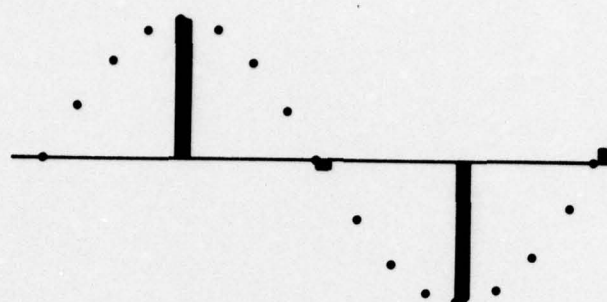
(a)
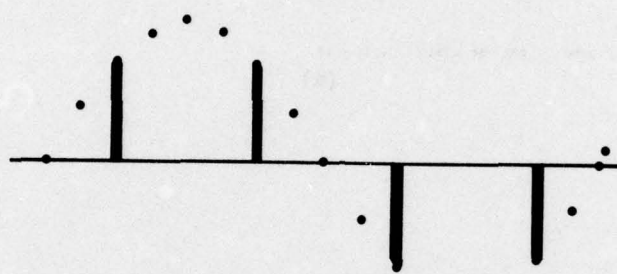
(b)

TM RESPONSE VALUES

Sample Interval	a	b
1	83	60
2	60	60
3	40	60
4	60	60

(c)

Figure 18. Demonstration of the Source of the Modulation in Simulation POHs when the Model's Stimulus is a 1263 Hz Tone Sampled at 0.2 msec Intervals.

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Figures 19 and 20 present the PIHs computed from the tone-on-segments of the responses of the models juxtaposed with the corresponding neuron PIHs.

The Glot-1 stimulus presented to the models was 3B. This speech-like sound is comprised of the concatenation of approximately 40 msec segments of the spoken vowels /ɔ/, /r/, /i/, /o/, and /ə/. For simulation, 3B was passed through ROC COC and the response of channel 20, which has a peak frequency of 1111 Hz, was chosen as the stimulus to the TM. Figure 21 presents this response juxtaposed with the POH constructed from the responses of the neuron to 100 presentations of 3B at an intensity of 10 dB attenuation. Note that the POH generally follows the displacement of the ROC COC channel 20 response. * Figure 21 also presents the POH of the 03/31/76.3 model generated using the same stimulus.

For each model and for the neuron, PIHs were constructed from the segments of the responses corresponding to each of the vowels. These PIHs are juxtaposed by vowel in Figures 22 through 26.

The POH and PIH computed from the spontaneous activity of the 03/31/76.3 model is shown in Figure 27.

6.3   PERFORMANCE CRITERIA FOR SELECTING THE BEST MODEL

A semiquantitative procedure, Procedure C, has been developed for use in deciding which of the five models provides the best fit to neuron 710827/11's behavior. The procedure relies on subjective judgment to provide the initial partition of the models into better-fit and poorer-fit groups. The better-fit group is then ranked using performance criteria taken from a summary of the PIHs called the Peak Occurrence Table. Generally this table has a column for each PIH being compared; in this case one column for the neuron and one column for each model. Table 4 is an example. The rows are associated with interpulse intervals. For each PIH, an entry is made in the row associated with each interpulse interval where a peak occurs in the PIH. A peak is defined as any change from positive to negative slope in the PIH. The entry made is the probability of that peak and its two immediately adjacent sample intervals (the error of the data acquisition system is ± 1 sample interval):

$$p_{peak}(i) = p_{PIH}(i-1) + p_{PIH}(i) + p_{PIH}(i+1)$$

where $p_{PIH}(.)$ is the normalized PIH and i is the sample interval in which the peak occurred. Where the peak is more than one sample interval wide, the peak is defined to occur in the interpulse interval with the largest probability is computed above.

---

*The correlation is improved by correcting the POH for an approximately 0.2 msec per 40 msec clock error in the data.

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Figure 19. Pulse Interval Histograms Computed from the Tone-On Segments of Responses to 100 Presentations of a 63 dB Attenuation, 1263 Hz Pure Tone.

(a) Neuron 710827/11, Run 24.

(b) Model 03/20/76.3.

(c) Model 03/22/76.3.

(d) Model 03/24/76.3.

(e) Model 03/24/76.5.

(f) Model 03/31/76.3.

(a) FIGURE 710827 . 11., 24.
DEFINING INTERVALS 70 TO 530 NUMBER OF INTERVALS = 505
AVERAGE = 12.99

(b) FIGURE BASSETT.J . 03/20/76.3. 2.
DEFINING INTERVALS 151 TO 550 NUMBER OF INTERVALS = 457
AVERAGE = 13.12

(c) FIGURE BASSETT.J . 03/22/76.3. 2.
DEFINING INTERVALS 151 TO 550 NUMBER OF INTERVALS = 442
AVERAGE = 13.68

(d) FIGURE BASSETT.J . 03/24/76.5. 2.
DEFINING INTERVALS 151 TO 550 NUMBER OF INTERVALS = 481
AVERAGE = 12.25

(e) FIGURE BASSETT.J . 03/24/76.3. 2.
DEFINING INTERVALS 151 TO 550 NUMBER OF INTERVALS = 494
AVERAGE = 12.23

(f) FIGURE BASSETT.J . 03/31/76.3. 2.
DEFINING INTERVALS 151 TO 550 NUMBER OF INTERVALS = 495
AVERAGE = 12.40

49
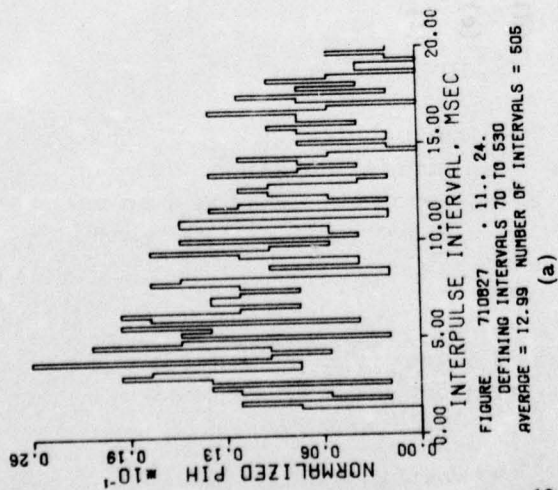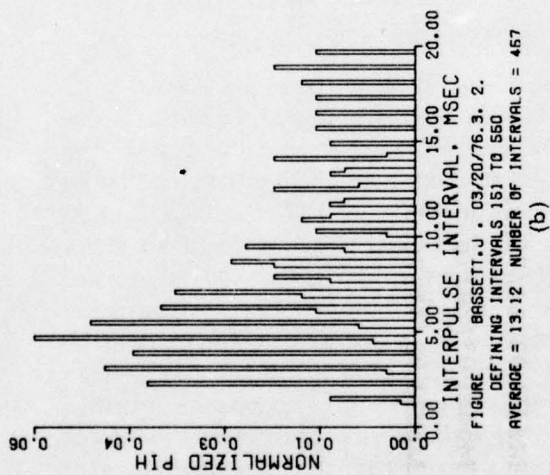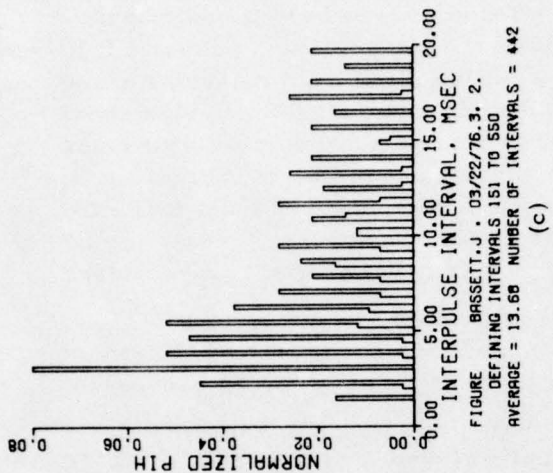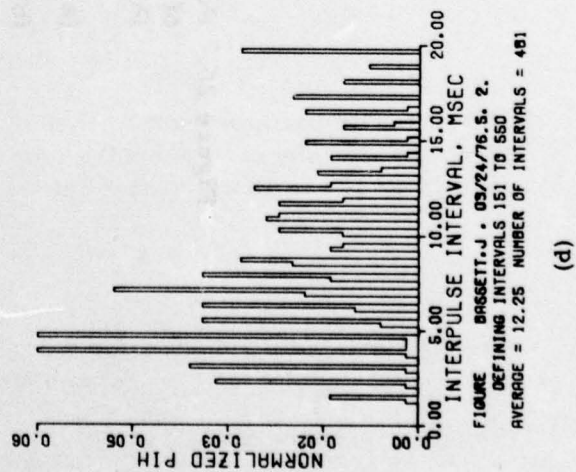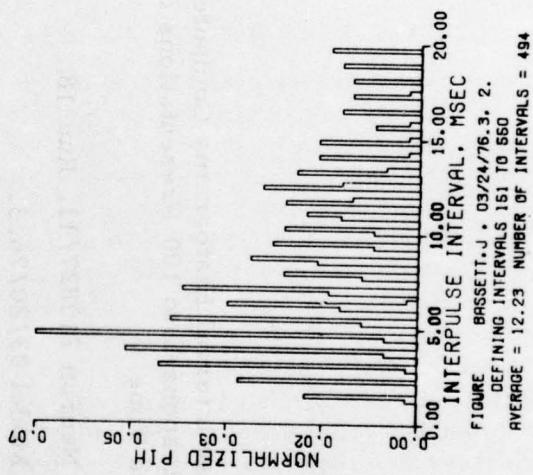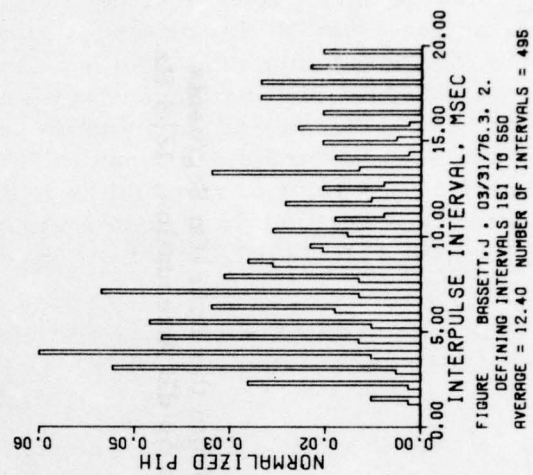
Figure 20. Pulse Interval Histograms Computed from the Tone-On Segments of Responses to 100 Presentations of a 50 dB Attenuation, 1263 Hz Pure Tone.

(a) Neuron 710827/11, Run 18.

(b) Model 03/20/76.3.

(c) Model 03/22/76.3.

(d) Model 03/24/76.3.

(e) Model 03/24/76.5.

(f) Model 03/31/76.3.

(a) FIGURE 710827 , 11., 18.
DEFINING INTERVALS 70 TO 530
AVERAGE = 6.89 NUMBER OF INTERVALS = 1122

(b) FIGURE BASSETT.J . 03/20/76.3. 3.
DEFINING INTERVALS 151 TO 550
AVERAGE = 7.31 NUMBER OF INTERVALS = 931

(c) FIGURE BASSETT.J . 03/22/76.3. 3.
DEFINING INTERVALS 151 TO 550
AVERAGE = 7.59 NUMBER OF INTERVALS = 879

(d) FIGURE BASSETT.J . 03/24/76.3. 3.
DEFINING INTERVALS 151 TO 550
AVERAGE = 7.09 NUMBER OF INTERVALS = 968

(e) FIGURE BASSETT.J . 03/24/76.5. 3.
DEFINING INTERVALS 151 TO 550
AVERAGE = 7.07 NUMBER OF INTERVALS = 977

(f) FIGURE BASSETT.J . 03/31/76.3. 3.
DEFINING INTERVALS 151 TO 550
AVERAGE = 6.86 NUMBER OF INTERVALS = 1006

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Figure 21.

    (a) The Response of ROC COC Channel 20 to Stimulus 3B. Magnitude Units have no Significance.

    (b) The POH Constructed from Neuron 710827/11's Responses to 100 Presentation of Stimulus 3B.

    (c) The POH Constructed from Model 03/31/76.3's Responses to 100 Presentations of the ROC COC Channel 20 Response to Stimulus 3B.
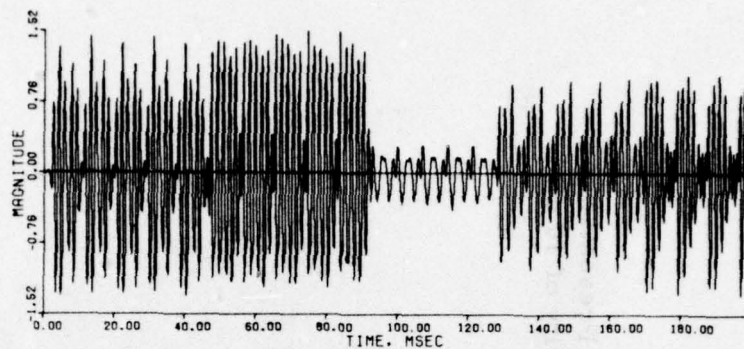
FIGURE   TM STIMULUS FOR 38   . 10.

(a)

FIGURE   POH FOR 710827   . 11.. 7.

(b)
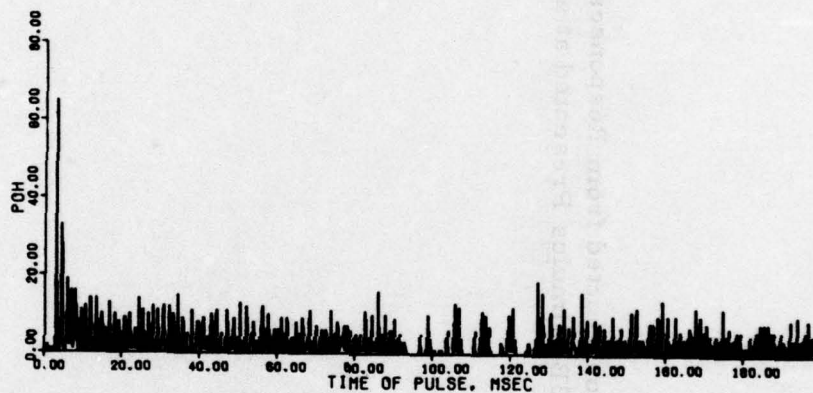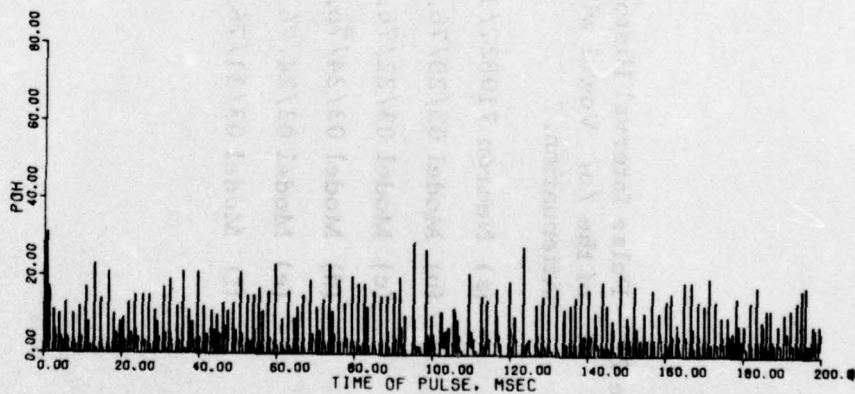
FIGURE   POH FOR BASSETT.J . 03/31/76.3. 4.

(c)

Figure 22. Pulse Interval Histograms Constructed from Responses to 100 Presentations of the /ɔ/ Vowel within the 3B Stimulus Presented at an Intensity of 10 dB Attenuation.

(a) Neuron 710827/11.

(b) Model 03/20/76.3.

(c) Model 03/22/76.3.

(d) Model 03/24/76.3.

(e) Model 03/24/76.5.

(f) Model 03/31/76.3.

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FIGURE 710827 . 11 . 7 .
DEFINING INTERVALS 15 TO 233
AVERAGE = 4.38 NUMBER OF INTERVALS = 842

(a)

FIGURE BASSETT.J . 03/20/76.3. 4.
DEFINING INTERVALS 15 TO 233
AVERAGE = 6.74 NUMBER OF INTERVALS = 452

(b)

FIGURE BASSETT.J . 03/22/76.3. 4.
DEFINING INTERVALS 15 TO 233
AVERAGE = 7.30 NUMBER OF INTERVALS = 421

(c)

FIGURE BASSETT.J . 03/24/76.3. 4.
DEFINING INTERVALS 15 TO 233
AVERAGE = 6.56 NUMBER OF INTERVALS = 484

(d)

FIGURE BASSETT.J . 03/24/76.5. 4.
DEFINING INTERVALS 15 TO 233
AVERAGE = 6.73 NUMBER OF INTERVALS = 464

(e)

FIGURE BASSETT.J . 03/31/76.3. 4.
DEFINING INTERVALS 15 TO 233
AVERAGE = 6.63 NUMBER OF INTERVALS = 481

(f)

Figure 23. Pulse Interval Histograms Constructed from Responses to 100 Presentations of the /r/ Vowel within the 3B Stimulus Presented at an Intensity of 10 dB Attenuation.

(a) Neuron 710827/11.

(b) Model 03/20/76.3.

(c) Model 03/22/76.3.

(d) Model 03/24/76.4.

(e) Model 03/24/76.5.

(f) Model 03/31/76.3.

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INTERPULSE INTERVAL. MSEC

FIGURE 710827 . 11.. 7.
DEFINING INTERVALS 234 TO 459
AVERAGE = 6.07 NUMBER OF INTERVALS = 572

(a)

FIGURE BASSETT.J . 03/20/76.3. 4.
DEFINING INTERVALS 234 TO 459
AVERAGE = 6.43 NUMBER OF INTERVALS = 513

(b)

FIGURE BASSETT.J . 03/22/76.3. 4.
DEFINING INTERVALS 234 TO 459
AVERAGE = 6.84 NUMBER OF INTERVALS = 475

(c)

FIGURE BASSETT.J . 03/24/76.3. 4.
DEFINING INTERVALS 234 TO 459
AVERAGE = 6.79 NUMBER OF INTERVALS = 496

(d)

FIGURE BASSETT.J . 03/24/76.5. 4.
DEFINING INTERVALS 234 TO 459
AVERAGE = 6.49 NUMBER OF INTERVALS = 534

(e)

FIGURE BASSETT.J . 03/31/76.3. 4.
DEFINING INTERVALS 234 TO 459
AVERAGE = 6.51 NUMBER OF INTERVALS = 527

(f)

Figure 24. Pulse Interval Histograms Constructed from Responses to 100 Presentations of the /i/ Vowel within the 3B Stimulus Presented at an Intensity of 10 dB Attenuation.

(a) Neuron 710827/11.

(b) Model 03/20/76.3.

(c) Model 03/22/76.3.

(d) Model 03/24/76.3.

(e) Model 03/24/76.5.

(f) Model 03/31/76.3.

FIGURE 71DB27 , 11., 7.
DEFINING INTERVALS 460 TO 640
AVERAGE = 8.46 NUMBER OF INTERVALS = 189

(a)

FIGURE BASSETT,J , 03/20/76.3. 4.
DEFINING INTERVALS 460 TO 640
AVERAGE = 6.21 NUMBER OF INTERVALS = 392

(b)

FIGURE BASSETT,J , 03/22/76.3. 4.
DEFINING INTERVALS 460 TO 640
AVERAGE = 6.99 NUMBER OF INTERVALS = 342

(c)

FIGURE BASSETT,J , 03/24/76.3. 4.
DEFINING INTERVALS 460 TO 640
AVERAGE = 6.34 NUMBER OF INTERVALS = 370

(d)

FIGURE BASSETT,J , 03/24/76.5. 4.
DEFINING INTERVALS 460 TO 640
AVERAGE = 6.37 NUMBER OF INTERVALS = 368

(e)

FIGURE BASSETT,J , 03/31/76.3. 4.
DEFINING INTERVALS 460 TO 640
AVERAGE = 6.34 NUMBER OF INTERVALS = 386

(f)

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Figure 25. Pulse Interval Histograms Constructed from Responses to 100 Presentations of the /o/ Vowel within the 3B Stimulus Presented at an Intensity of 10 dB Attenuation.

(a) Neuron 710827/11.

(b) Model 03/20/76.3.

(c) Model 03/22/76.3.

(d) Model 03/24/76.3.

(e) Model 03/24/76.5.

(f) Model 03/31/76.3.

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FIGURE 710627 . 11..7.
DEFINING INTERVALS 641 TO 849
AVERAGE = 6.51 NUMBER OF INTERVALS = 496

(a)

FIGURE BASSETT.J. 03/20/76.3. 4.
DEFINING INTERVALS 641 TO 849
AVERAGE = 6.47 NUMBER OF INTERVALS = 453

(b)

FIGURE BASSETT.J. 03/22/76.3. 4.
DEFINING INTERVALS 641 TO 849
AVERAGE = 6.74 NUMBER OF INTERVALS = 441

(c)

FIGURE BASSETT.J. 03/24/76.3. 4.
DEFINING INTERVALS 641 TO 849
AVERAGE = 6.30 NUMBER OF INTERVALS = 464

(d)

FIGURE BASSETT.J. 03/24/76.5. 4.
DEFINING INTERVALS 641 TO 849
AVERAGE = 6.35 NUMBER OF INTERVALS = 472

(e)

FIGURE BASSETT.J. 03/31/76.3. 4.
DEFINING INTERVALS 641 TO 849
AVERAGE = 6.56 NUMBER OF INTERVALS = 479

(f)

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Figure 26. Pulse Interval Histograms Constructed from Responses to 100 Presentations of the /ə/ Vowel within the 3B Stimulus Presented at an Intensity of 10 dB Attenuation.

(a) Neuron 710827/11.

(b) Model 03/20/76. 3.

(c) Model 03/22/76. 3.

(d) Model 03/24/76. 3.

(e) Model 03/24/76. 5.

(f) Model 03/31/76. 3.

(a) INTERPULSE INTERVAL, MSEC — NORMALIZED PIH
FIGURE 710827 , 11., 7.
DEFINING INTERVALS 850 TO 999
AVERAGE = 6.49   NUMBER OF INTERVALS = 243

(b) INTERPULSE INTERVAL, MSEC — NORMALIZED PIH
FIGURE   BASSETT.J . 03/20/76.3. 4.
DEFINING INTERVALS 850 TO 999
AVERAGE = 6.29   NUMBER OF INTERVALS = 307

(c) INTERPULSE INTERVAL, MSEC — NORMALIZED PIH
FIGURE   BASSETT.J . 03/22/76.3. 4.
DEFINING INTERVALS 850 TO 999
AVERAGE = 6.21   NUMBER OF INTERVALS = 314

(d) INTERPULSE INTERVAL, MSEC — NORMALIZED PIH
FIGURE   BASSETT.J . 03/24/76.3. 4.
DEFINING INTERVALS 850 TO 999
AVERAGE = 5.67   NUMBER OF INTERVALS = 334

(e) INTERPULSE INTERVAL, MSEC — NORMALIZED PIH
FIGURE   BASSETT.J . 03/24/76.5. 4.
DEFINING INTERVALS 850 TO 999
AVERAGE = 5.72   NUMBER OF INTERVALS = 320

(f) INTERPULSE INTERVAL, MSEC — NORMALIZED PIH
FIGURE   BASSETT.J . 03/31/76.3. 4.
DEFINING INTERVALS 850 TO 999
AVERAGE = 6.11   NUMBER OF INTERVALS = 316

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FIGURE   POH FOR BASSETT.J . 03/31/76.3. 1.

FIGURE   BASSETT.J . 03/31/76.3. 1.
DEFINING INTERVALS 1 TO 999
AVERAGE = 15.69   NUMBER OF INTERVALS = 1176

Figure 27.   The Pulse Occurrence Histogram (Top) and the Pulse
Interval Histogram of the Spontaneous Activity of Model
03/31/76.3.

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One performance criterion is to count the number of matching peaks in each model, where a peak in a model PIH is said to match a peak in the neuron PIH if the peaks occur within one sample interval of each other. The model with the most number of matching peaks receives the highest rank (1), the model with the next highest number of matching peaks receives the next highest rank (2), and so on.

Any ties in this procedure are resolved by the second performance criterion. For each model, and for each matching peak, the absolute value of the difference between the $p_{peak}(i)$ value of the model and the neuron is divided by the $p_{peak}(i)$ value of the model to give the fraction error in the probability of occurrence of that peak. These values are added for each model involved in the tie and the model with the lowest total value is given the highest rank.

6.4 THE BEST MODEL

Procedure C was used to select the best model from the five models whose behavior was presented in Section 6.2. For the tone behavior, since all the peaks of the models and the neuron matched, the selection procedure is a mix of subjective judgment and quantitative measure of the fraction error in the peaks. Tables 2 and 3 summarize the results of the analysis: 03/31/76.3 and 03/24/76.5 were ranked 1 and 2 in both cases, with 03/20/76.3 and 03/24/76.3 tied for third position.

Peak Occurrence Tables, Tables 4 through 8, were constructed for each of the vowel sounds presented to the models and the neurons. These were used in Procedure C to produce the rankings summarized in Table 9. It is clear from this table that model 03/31/76.3 is the best model.

PROCEDURE C
SELECT THE BEST MODEL

1. Do the following for each vowel-PIH and tone-on segment PIH:

   a. Select two or three models that, by eyeball judgment, fit the corresponding neuron PIH better than the others.

   b. Rank these models according to the number of peaks that match (occur within one sample interval of each other). The one(s) with the greatest number of matching peaks is (are) assigned the highest rank.

   c. Resolve any ties in (b) by computing the total fraction error in probability at a matching peak which is given by:

$$\frac{\text{probability associated with peak in neuron PIH - probability associated with peak in model PIH}}{\text{probability associated with peak in neuron PIH}}$$

   The model with the lowest total error receives the highest rank.

2. For each model, add up the ranks for each vowel and tone-on segment PIH. The best model is the one with the lowest total score.

TABLE 2

MODEL RANKS BASED ON 63 dB TONE ONLY

Rank	Model
1	03/31/76.3
2	03/24/76.5
3	03/20/76.3
4	03/22/76.3
5	03/24/76.3

TABLE 3

MODEL RANKS BASED ON 50 dB TONE ONLY

Rank	Model
1	03/31/76.3
2	03/24/76.5
3	03/24/76.3
4	03/20/76.3
5	03/22/76.3

TABLE 4

PEAK OCCURRENCE TABLE FOR VOWEL /ɔ/
(Stimulus 3B, 10 dB Attenuation; Vowel Located in First Position)

Interpulse Interval	Neuron 710827/11/7	3/20/76.3	3/22/76.3	3/24/76.3	3/24/76.5	3/31/76.3
1.2						
1.4	.270					
1.6		.093	.102	.107	.083	.071
1.8						
2.0		.106	.088			.094
2.2				.087	.070	
2.4	.112					
2.6						
2.8						
3.0		.100	.078			
3.2					.105	.075
3.4						
3.6	.091	.053		.136		
3.8			.074		.093	.121
4.0						
4.2						
4.4						
4.6						
4.8	.082					
5.0		.066			.064	.096
5.2				.085		
5.4			.076			
5.6						.060
5.8			.052			
6.0						
6.2	.046					

Average	4.38	6.74	7.30	6.56	6.73	6.63
Number Pulses	842	452	421	484	464	481
Number Matching Peaks	5	3	2	3	4	3

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TABLE 5

PEAK OCCURRENCE TABLE FOR VOWEL /ɹ/
(Stimulus 3B, 10 dB Attenuation; Vowel Located in Second Position)

Interpulse Interval	Neuron 710827/11/7	3/20/76.3	3/22/76.3	3/24/76.3	3/24/76.5	3/31/76.3
1.2						
1.4						
1.6	.159		.145			.110
1.8		.142		.106	.127	
2.0						
2.2				.076		
2.4	.118	.070	.053		.066	.076
2.6						
2.8						
3.0						
3.2	.098	.119				
3.4			.105	.157	.129	.129
3.6						
3.8					.114	
4.0		.070	.084	.064		.078
4.2	.052					
4.4						
4.6	.081					
4.8						
5.0		.064	.072	.058	.075	.072
5.2						
5.4						
5.6	.059				.071	.055
5.8		.051	.044	.072		
6.0						

Average	6.07	6.43	6.84	6.79	6.49	6.51
Number Pulses	572	513	475	498	534	527
Number Matching Peaks	6	5	5	5	4	5

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TABLE 6

PEAK OCCURRENCE TABLE FOR VOWEL /i/
(Stimulus 3B, 10 dB Atenuation; Vowel Located in Third Position)

Interpulse Interval	Neuron 710827/11/7	3/20/76.3	3/22/76.3	3/24/76.3	3/24/76.5	3/31/76.3
1.0						
1.2	.048					.028
1.4		.051				
1.6				.043	.071	.054
1.8	.069		.050			
2.0						
2.2		.071			.057	.049
2.4			.073	.089		
2.6		.048				
2.8	.037			.070		
3.0						
3.2				.135		
3.4		.207			.155	
3.6	.026		.146			.153
3.8				.078		
4.0						
4.2	.032					.062
4.4		.064		.049		
4.6			.053		.038	
4.8						
5.0						.031
5.2					.046	
5.4						.036
5.6	.064	.043				
5.8			.053	.041	.041	.044
6.0	.053					
6.8		.064	.064			
7.0	.111			.103	.109	.098
7.2		.051	.076			
7.4	.079					

	Neuron 710827/11/7	3/20/76.3	3/22/76.3	3/24/76.3	3/24/76.5	3/31/76.3
Average	8.46	6.21	6.99	6.34	6.37	6.34
Number Pulses	189	392	342	370	368	386
Number Matching Peaks	9	7	5	6	4	7

TABLE 7

PEAK OCCURRENCE TABLE FOR VOWEL /o/
(Stimulus 3B, 10 dB Attenuation; Vowel Located in Fourth Position)

Interpulse Interval	Neuron 710827/11/7	3/20/76.3	3/22/76.3	3/24/76.3	3/24/76.5	3/31/76.3
1.2						
1.4	.089					
1.6						
1.8		.141	.129	.142	.140	.121
2.0	.079					
2.2						
2.4	.099					
2.6						.054
2.8				.080		
3.0			.082		.055	
3.2		.104				
3.4				.080		
3.6	.091	.088	.088		.089	.100
3.8				.084		
4.0		.075				
4.2			.073			.063
4.4						
4.6	.058	.079		.080	.078	.090
4.8						
5.0			.054			
5.2						
5.4						
5.6	.083				.051	.029
5.8						
6.0						

Average	6.51	6.47	6.74	6.30	6.35	6.56
Number Pulses	496	453	441	464	472	479
Number Matching Peaks	6	3	2	3	4	5

TABLE 8

PEAK OCCURRENCE TABLE FOR VOWEL /ə/
(Stimulus 3B, 10 dB Attenuation; Vowel Located in Fifth Position)

Interpulse Interval	Neuron 710827/11/7	3/20/76.3	3/22/76.3	3/24/76.3	3/24/76.5	3/31/76.3
1.0						.019
1.2	.074					
1.4						
1.6		.114	.105	.120	.081	.063
1.8	.095					
2.0						.082
2.2			.061	.060	.063	
2.4						
2.6	.107					
2.8		.081	.105	.102	.147	.136
3.0						
3.2			.099	.105	.144	.123
3.4						
3.6	.070	.085		.081		
3.8						
4.0						
4.2			.064	.078	.069	.076
4.4						
4.6	.045	.088			.072	
4.8				.072		
5.0	.033					
5.2						.044
5.4						
5.6		.075				
5.8			.076			.051
6.0	.074			.075	.094	

Average	6.49	6.29	6.21	5.67	5.72	6.11
Number Pulses	243	307	314	334	320	316
Number Matching Peaks	7	4	3	5	4	5

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TABLE 9

SUMMARY OF RANK FOR FIVE MODELS

	3/20/76.3	3/24/76.5	3/31/76.3
63 dB tone	3	2	1
50 dB tone	3	2	1
/ɔ/	2	1	3
/r/	1	3	2
/i/	2	3	1
/o/	3	2	1
/ə/	1	3	2
Total Rank	**15**	**16**	**11**

AN INTENSITY SERIES GENERATED BY THE MODEL

Model 03/31/76. 3 was presented with four different intensities of the 1263 Hz tone, with the stimulus structure being the same as described in the previous section. The POHs and PIHs computed from the Model's* responses to these tones are juxtaposed in Figures 28 through 31 with POHs and PIHs computed from the Neuron's responses to the same tones.

The following comparisons suggest that the Model performs well in simulating the Neuron. (All the following statements take into account the digitization errors introduced into the modeling effort.):

(1) The Neuron and Model PIH shapes are similar.

(2) The total number of pulses produced during the tone-on portion of the stimuli are close. About a 10% error is noted.

(3) The POHs are similar except in length of the suppression of activity following the tone.

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*In the remainder of this report, Model with a capital "M" will refer specifically to model 03/31/76. 3; Neuron with a capital "N" will refer to neuron 710827/11.
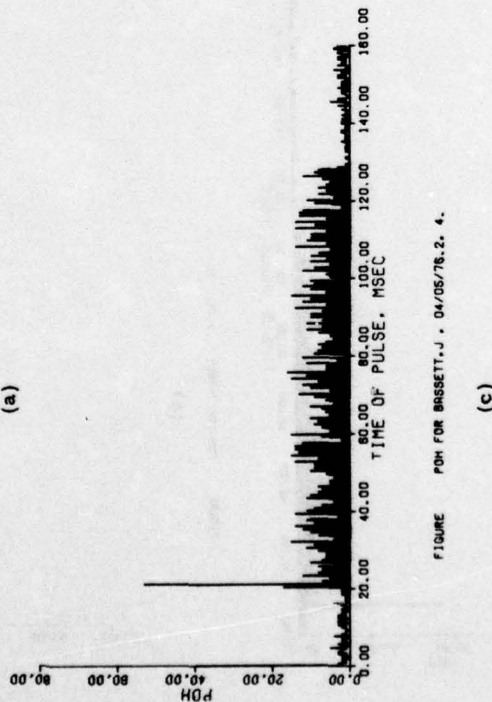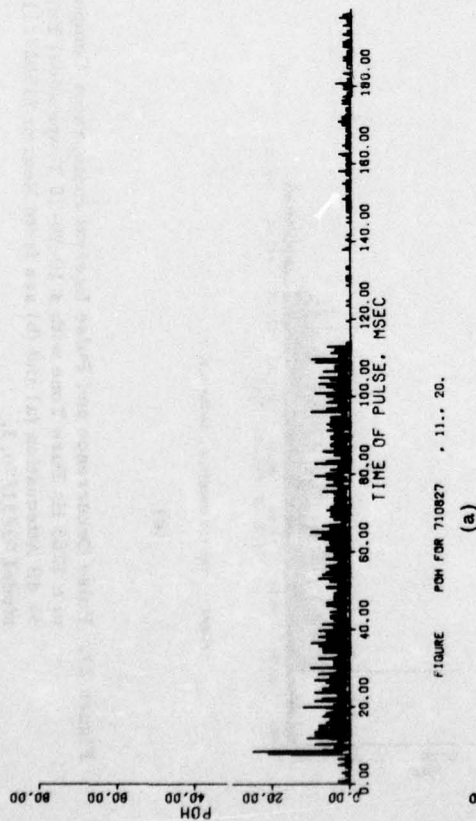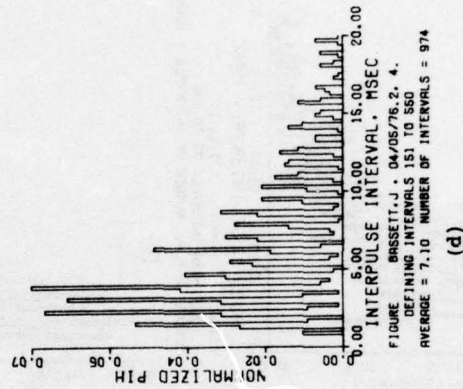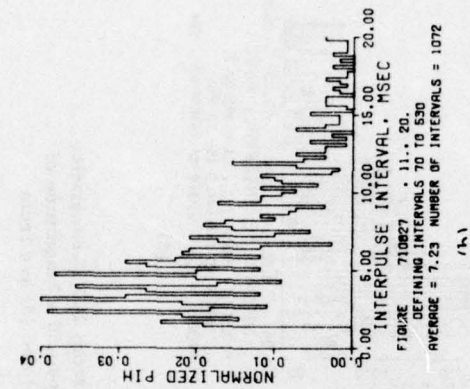
Figure 28. Pulse Occurrence and Pulse Interval Histograms Computed from 100 Presentation of a 1263 Hz Pure Tone with a 10-90-10 Trapezoidal Envelope and a Magnitude of 30 dB Attenuation (a) and (b) are from Neuron 710827/11, (c) and (d) are from Model 03/31/76.3.

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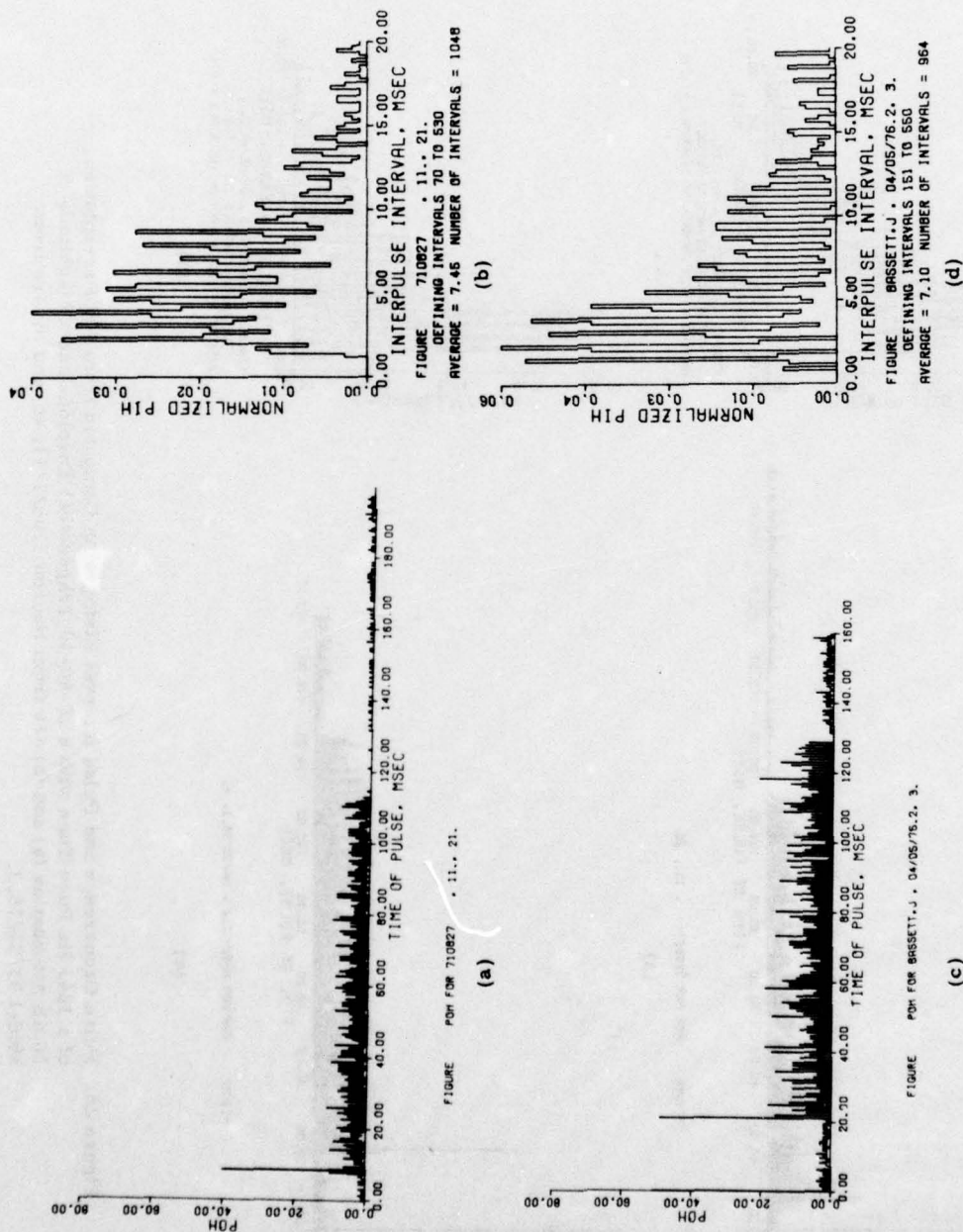
Figure 29. Pulse Occurrence and Pulse Interval Histograms Computed from 100 Presentation of a 1263 Hz Pure Tone with a 10-90-10 Trapezoidal Envelope and a Magnitude of 35 dB Attenuation (a) and (b) are from Neuron 710827/11, (c) and (d) are from Model 03/31/76.3.
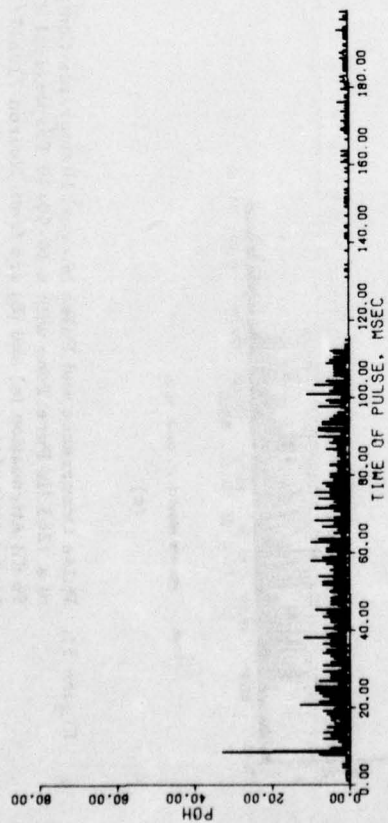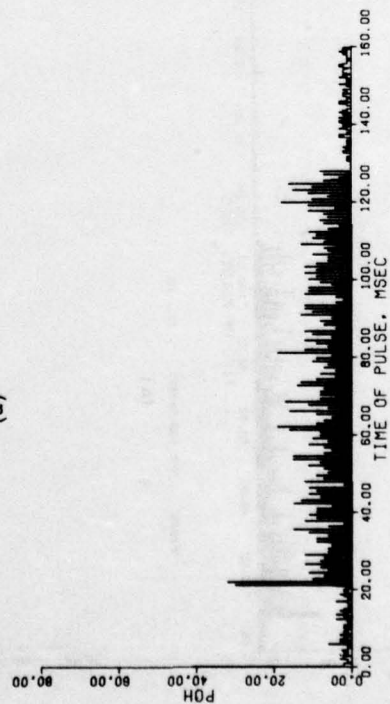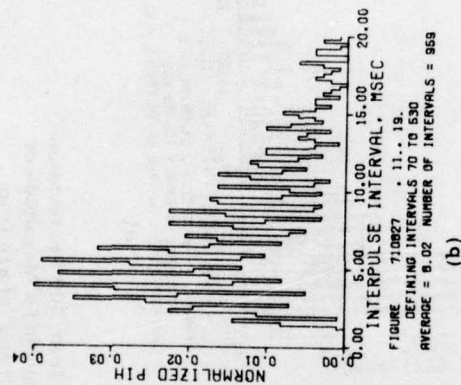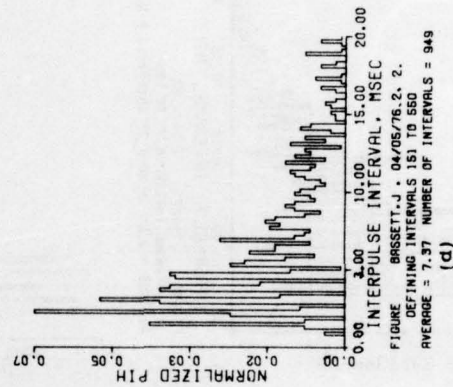
Figure 30. Pulse Occurrence and Pulse Interval Histograms Computed from 100 Presentation of a 1263 Hz Pure Tone with a 10-90-10 Trapezoidal Envelope and a Magnitude of 40 dB Attenuation (a) and (b) are from Neuron 710827/11, (c) and (d) are from Model 03/31/76.3.

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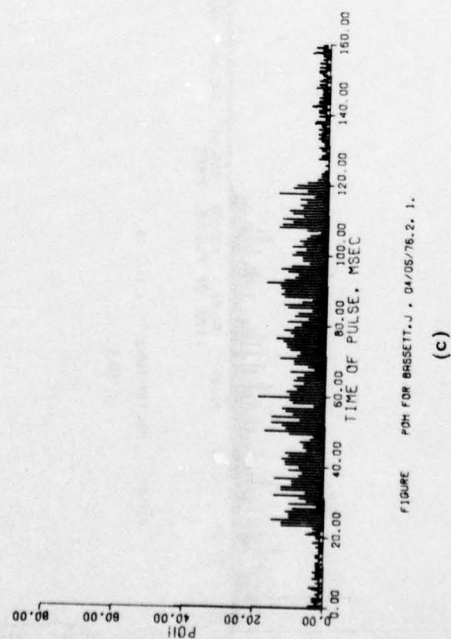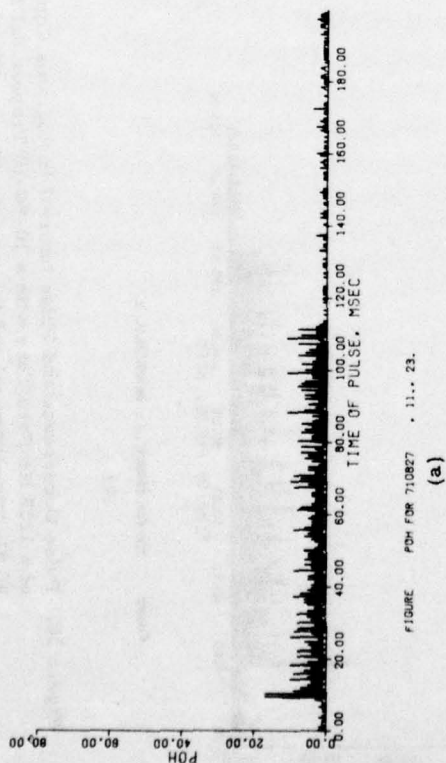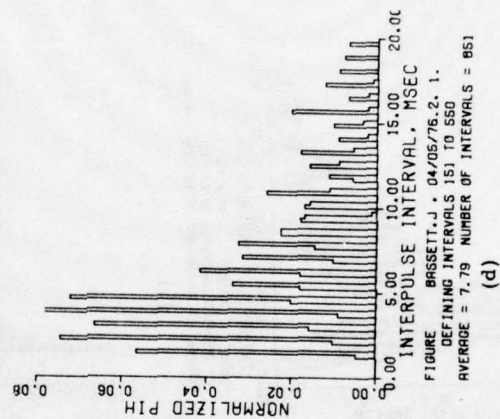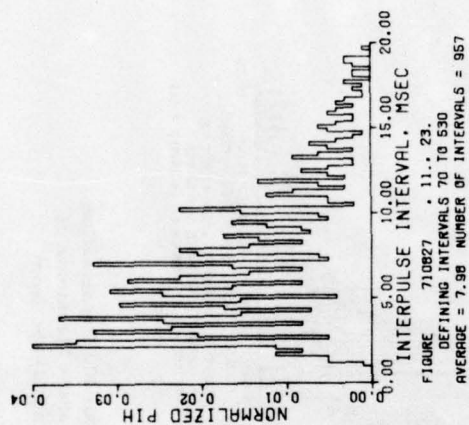
Figure 31. Pulse Occurrence and Pulse Interval Histograms Computed from 100 Presentation of a 1263 Hz Pure Tone with a 10-90-10 Trapezoidal Envelope and a Magnitude of 55 dB Attenuation (a) and (b) are from Neuron 710827/11, (c) and (d) are from Model 03/31/76.3.

SECTION 8

A COMPARISON OF MODEL AND NEURON RESPONSES
TO SPEECH-LIKE STIMULI

8.1 PULSE OCCURRENCE HISTOGRAMS

Model 03/31/76.3 was presented with the Glot-1 Stimuli listed in Table 10. Each of the eight pairs of Model and Neuron runs was comprised of 100 presentations of a stimulus. The stimuli, Neuron POHs and Model POHs are presented in Figure 32 through 39. Note that both the Neuron and Model POHs follow the displacement of the stimulus, with most of the activity occurring where the stimulus just crosses the time axis going positive. Also note that the model consistently has a large peak of activity before the start of the sound segment of the stimulus. This is due to a noise artifact on the representation of the stimulus seen by the model.

8.2 VOWEL PULSE INTERVAL HISTOGRAMS

For each run of the model and neuron, segment PIHs were constructed from those portions of the responses corresponding to each vowel segment in the stimulus. In the following discussion, such PIHs will be called vowel PIHs in general and a "vowel-name" followed by "PIH" in particular (e.g., /r/-PIH). They are presented in Figures 40 through 49 organized by vowel, with the Neuron vowel PIH on the left and the corresponding Model vowel PIH on the right in each figure. Note that there are four vowel PIHs for each vowel, corresponding to the fact that within the eight stimuli each vowel occurs four times. Also note that each vowel was presented twice at an intensity of 10 dB attenuation, and once each at intensities of 20 dB and 40 dB attenuation.

8.3 PEAK OCCURRENCE TABLES

Peak Occurrence Tables, Tables 11 through 20, have been constructed in order to facilitate the comparison of peak locations and magnitudes in comparable Neuron and Model vowel PIHs. These tables were constructed using the procedure outlined in Section 6.3. Only peaks occurring in an interpulse interval below 7.0 msec were included, since most of the interesting structure in the PIH takes place at interpulse intervals of less than 7.0 msec.

Ancillary information provided in the Peak Occurrence Tables include the intervals over which the vowel extends in the stimulus, the average interpulse interval, the total number of interpulse intervals, the stimulus the vowel is located in, the position of the vowel within the stimulus, and the stimulus intensity, in dB attenuation.

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Figure 32.

    (a) The Response of ROC COC's Channel 20 to Stimulus 3A, with a
        Magnitude of 10 dB Attenuation.

    (b) The POH Constructed from the Responses of Neuron 710827/11
        (Run 6) to 100 Presentations of the Stimulus in (a).

    (c) The POH Constructed from the Responses of Model 04/05/76.4
        (Run 1) to 100 Presentations of the Stimulus in (a).
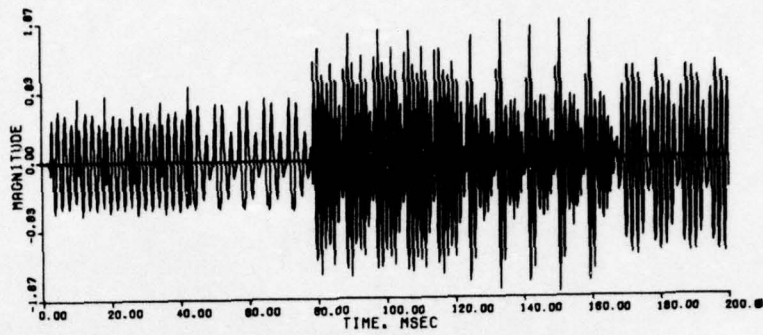
FIGURE   TM STIMULUS FOR 33A   10.
DEFINING INTERVALS 1 TO 900

(a)

FIGURE   POH FOR 710827   . 11.. 6.

(b)
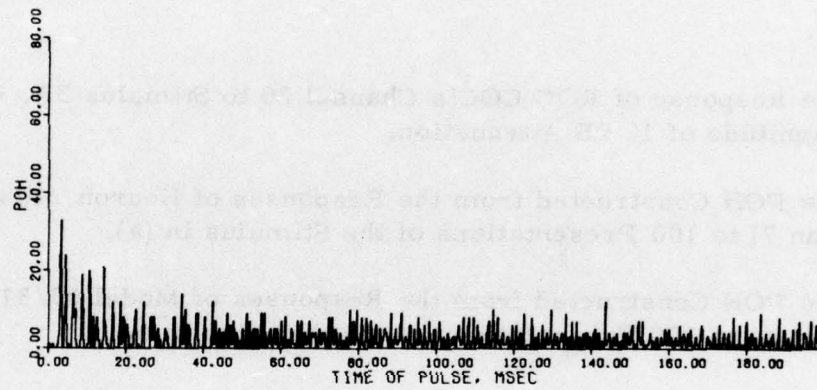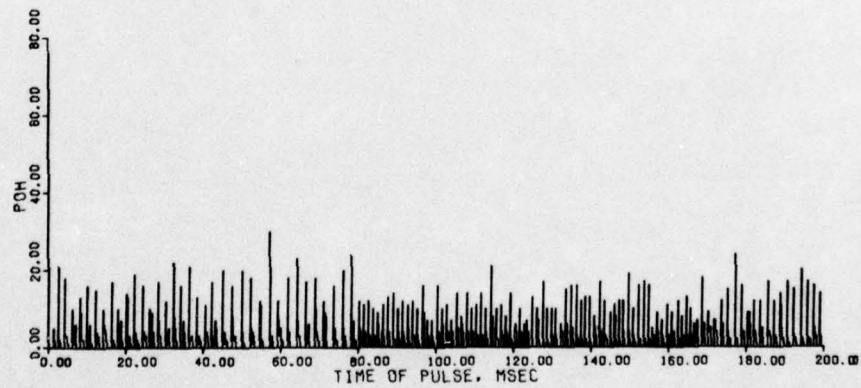
FIGURE   POH FOR BASSETT.J . 04/05/76.4. 1.

Figure 33.

(a) The Response of ROC COC's Channel 20 to Stimulus 3B, with a Magnitude of 10 dB Attenuation.

(b) The POH Constructed from the Responses of Neuron 710827/11 (Run 7) to 100 Presentations of the Stimulus in (a).

(c) The POH Constructed from the Responses of Model 03/31/76.3 (Run 4) to 100 Presentations of the Stimulus in (a).
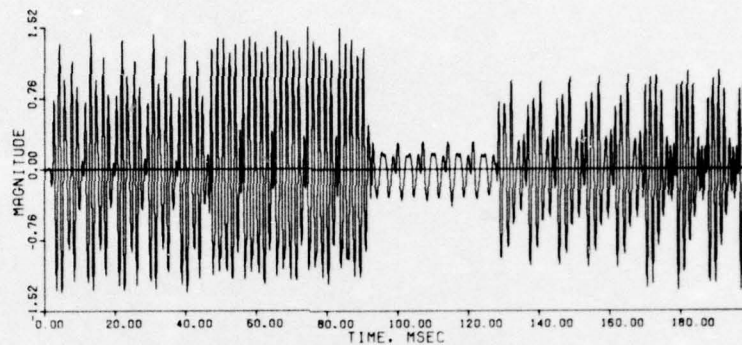
FIGURE   TM STIMULUS FOR 3B   . 10.

(a)

FIGURE   POH FOR 710827   . 11.. 7.

(b)

FIGURE   POH FOR BASSETT,J . 03/31/76.3. 4.

(c)

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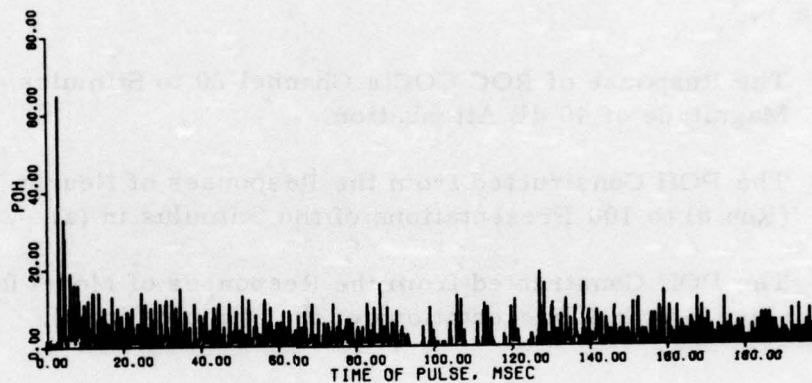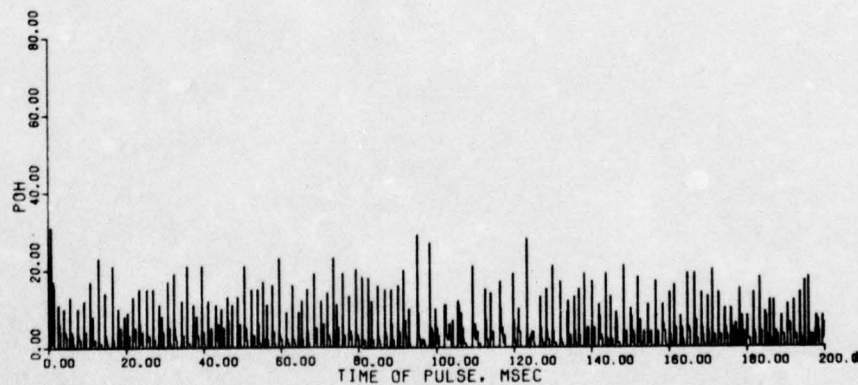
Figure 34.

(a) The Response of ROC COC's Channel 20 to Stimulus 4A, with a Magnitude of 40 dB Attenuation.

(b) The POH Constructed from the Responses of Neuron 710827/11 (Run 8) to 100 Presentations of the Stimulus in (a).

(c) The POH Constructed from the Responses of Model 04/15/76.3 (Run 1) to 100 Presentations of the Stimulus in (a).
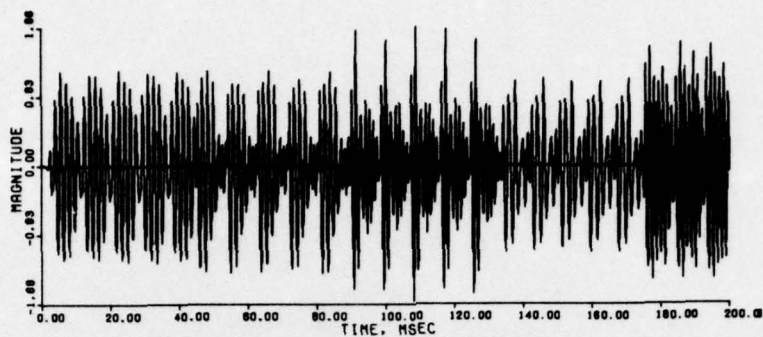
MAGNITUDE

TIME, MSEC

FIGURE   TM STIMULUS FOR 4A   10.
DEFINING INTERVALS 1 TO 800

(a)

POH

TIME OF PULSE, MSEC

FIGURE   POH FOR 710827   . 11.. 8.

(b)

POH

TIME OF PULSE, MSEC

FIGURE   POH FOR BASSETT.J . 04/15/76.3. 1.

(c)

85
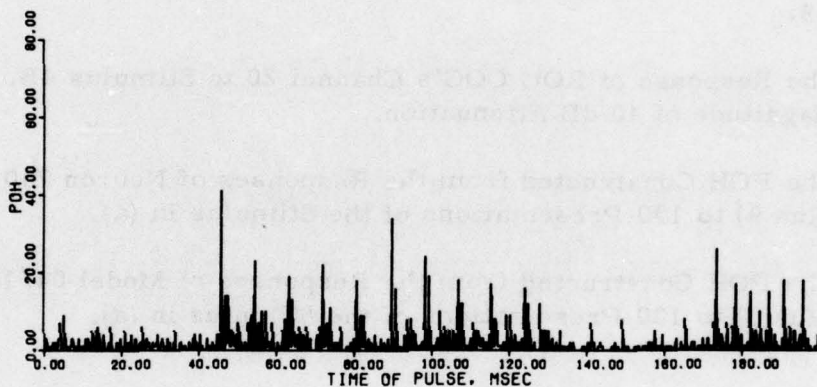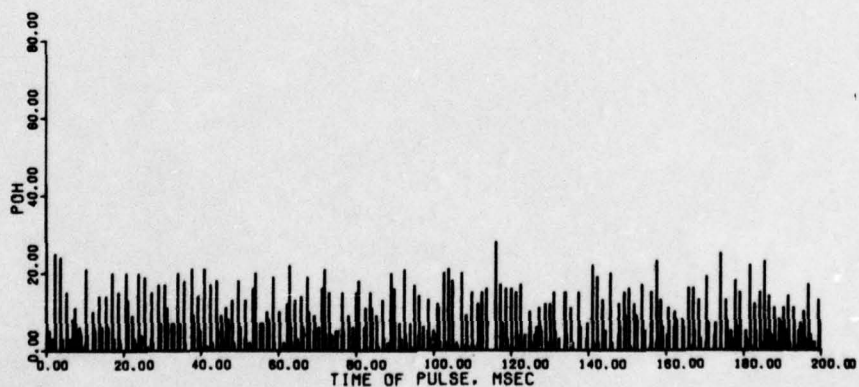
Figure 35.

(a) The Response of ROC COC's Channel 20 to Stimulus 4B, with a Magnitude of 40 dB Attenuation.

(b) The POH Constructed from the Responses of Neuron 710827/11 (Run 9) to 100 Presentations of the Stimulus in (a).

(c) The POH Constructed from the Responses of Model 04/12/76.3 (Run 1) to 100 Presentations of the Stimulus in (a).
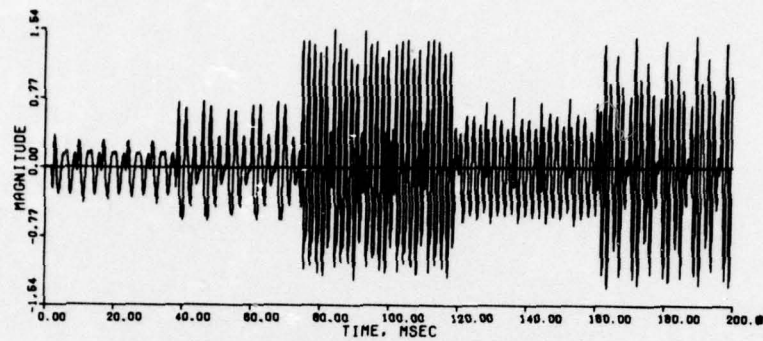
FIGURE   TM STIMULUS FOR 48   10.
DEFINING INTERVALS 1 TO 999

(a)
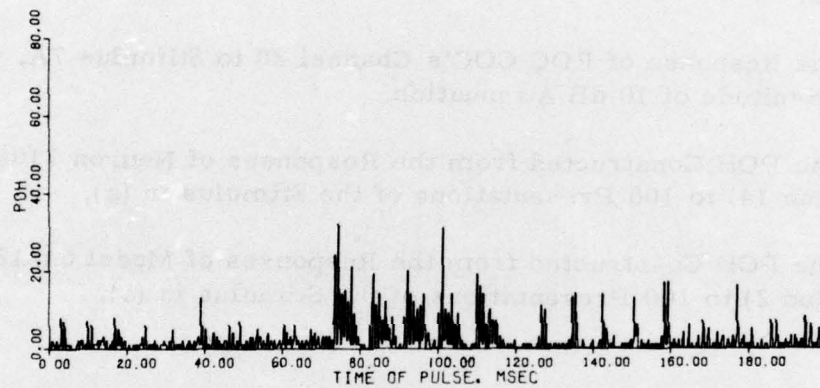
FIGURE   POH FOR 710827   . 11.. 9.

(b)
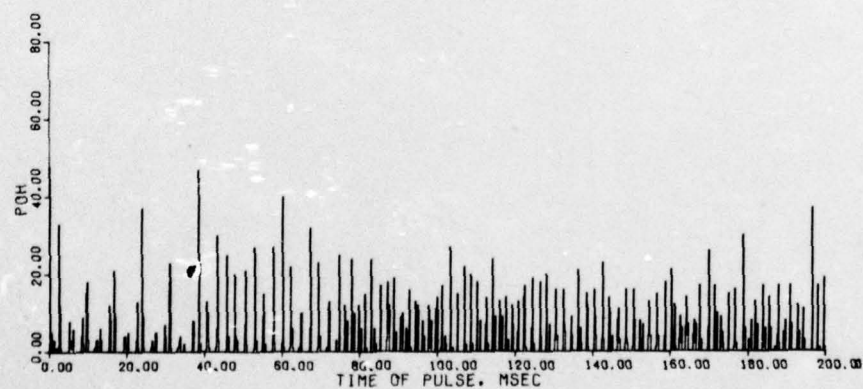
FIGURE   POH FOR BESSETT.J . 04/12/76.3. 1.

(c)

Figure 36.

(a) The Response of ROC COC's Channel 20 to Stimulus 7A, with a Magnitude of 10 dB Attenuation.

(b) The POH Constructed from the Responses of Neuron 710827/11 (Run 14) to 100 Presentations of the Stimulus in (a).

(c) The POH Constructed from the Responses of Model 04/12/76.3 (Run 2) to 100 Presentations of the Stimulus in (a).

FIGURE   TM STIMULUS FOR 7R   10.
DEFINING INTERVALS 1 TO 998

(a)

FIGURE   POH FOR 710827   . 11.. 14.

(b)
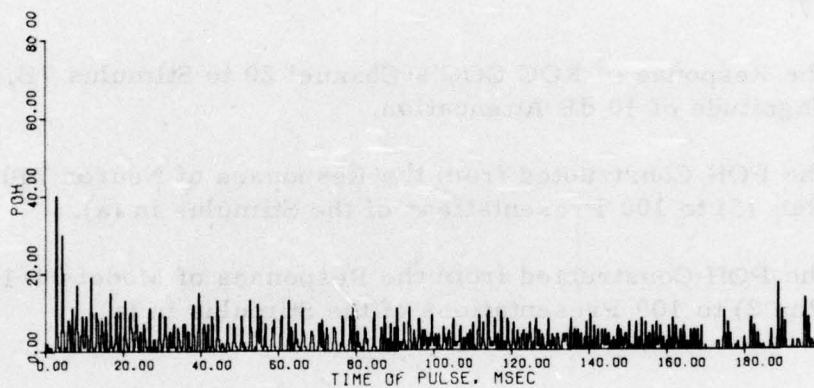
FIGURE   POH FOR BASSETT.J . 04/12/76.3. 2.

(c)

Figure 37.

    (a) The Response of ROC COC's Channel 20 to Stimulus 7B, with a
           Magnitude of 10 dB Attenuation.

    (b) The POH Constructed from the Responses of Neuron 710827/11
           (Run 15) to 100 Presentations of the Stimulus in (a).

    (c) The POH Constructed from the Responses of Model 04/15/76.3
           (Run 2) to 100 Presentations of the Stimulus in (a).

FIGURE   TM STIMULUS FOR 78   10.
DEFINING INTERVALS 1 TO 999

(a)
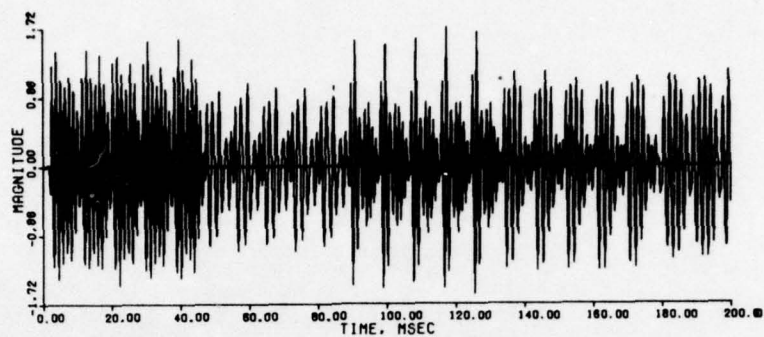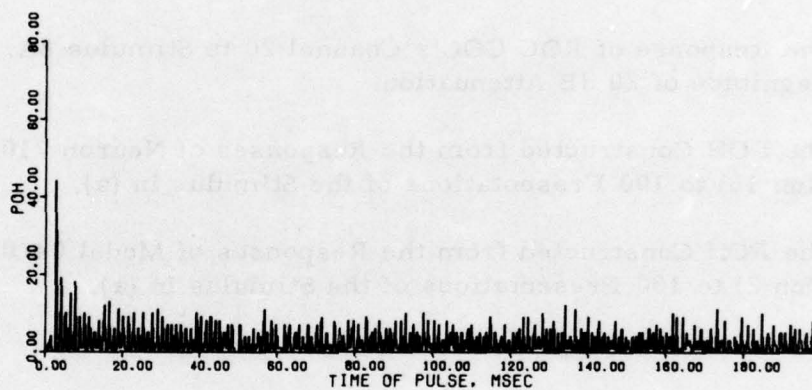
FIGURE   POH FOR 710827   . 11.. 15.

(b)
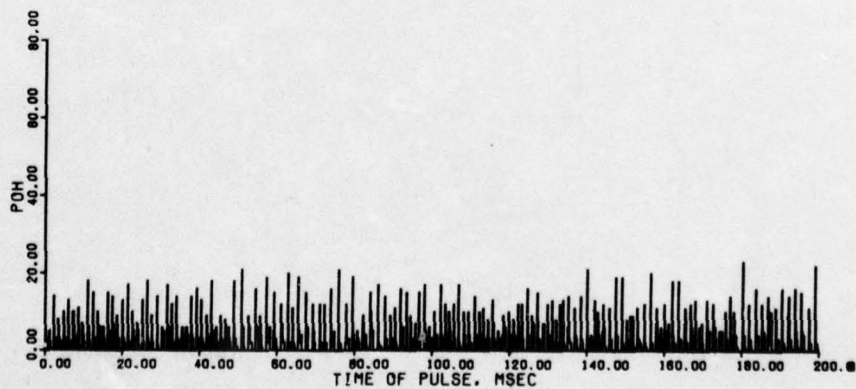
FIGURE   POH FOR BASSETT,J . 04/15/76.3. 2.

(c)

Figure 38.

    (a) The Response of ROC COC's Channel 20 to Stimulus 8A, with a
           Magnitude of 20 dB Attenuation.

    (b) The POH Constructed from the Responses of Neuron 710827/11
           (Run 16) to 100 Presentations of the Stimulus in (a).

    (c) The POH Constructed from the Responses of Model 04/05/76.4
           (Run 2) to 100 Presentations of the Stimulus in (a).

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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963
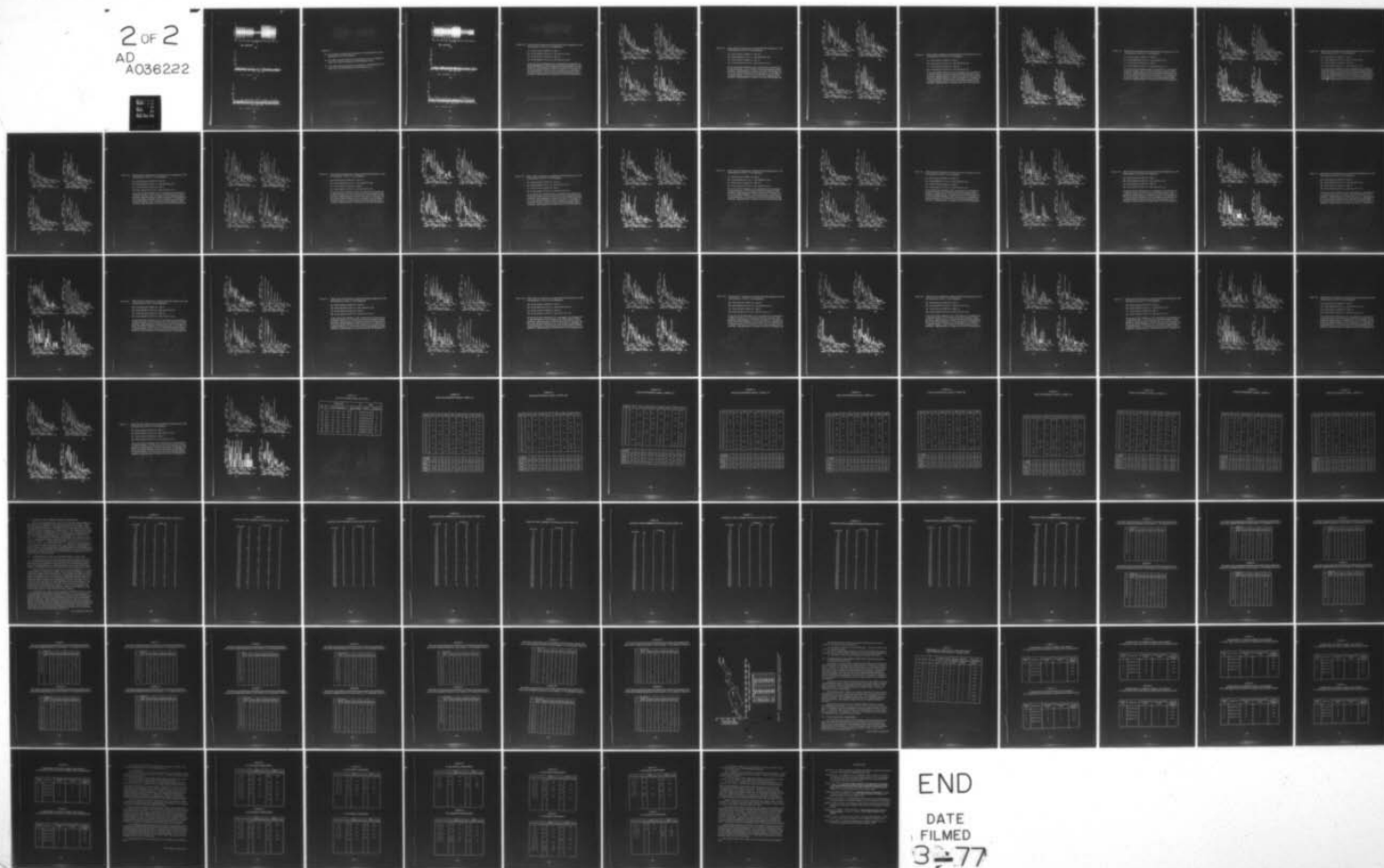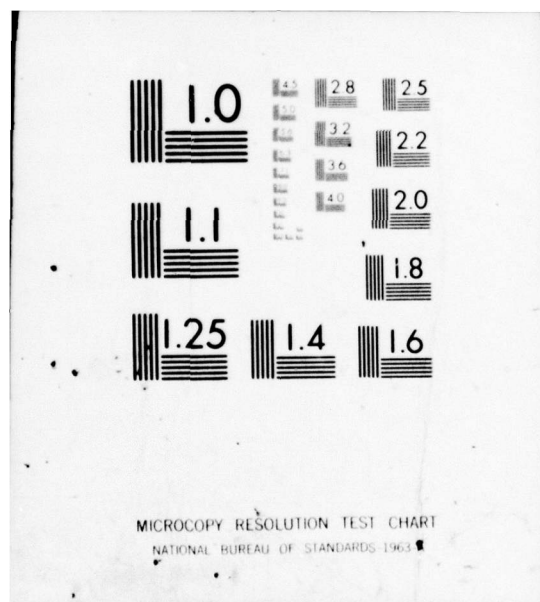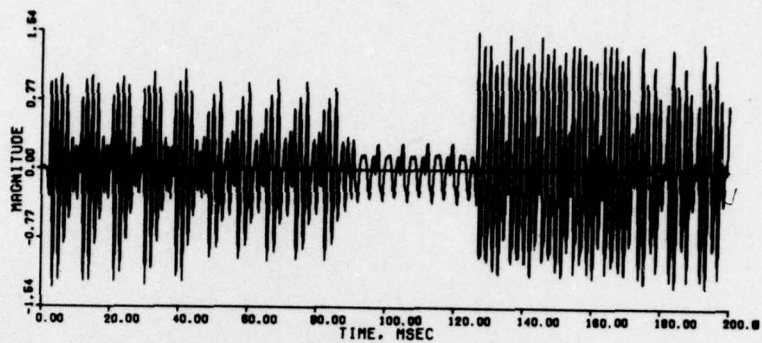
FIGURE   TM STIMULUS FOR BR   10.
DEFINING INTERVALS 1 TO 800

(a)
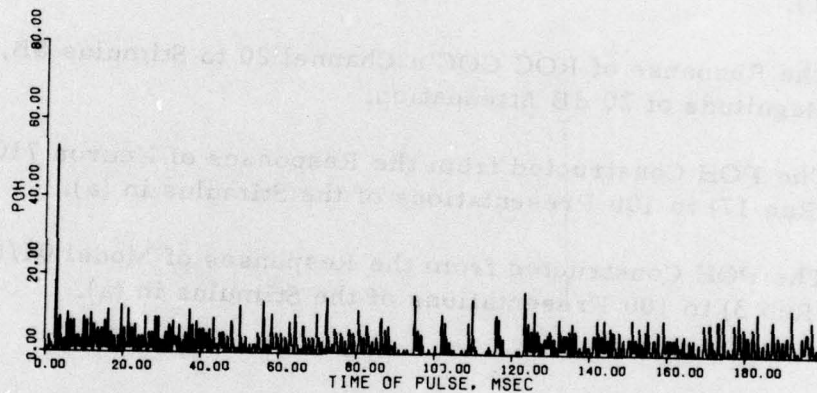
FIGURE   PDH FOR 710827   . 11.. 16.

(b)
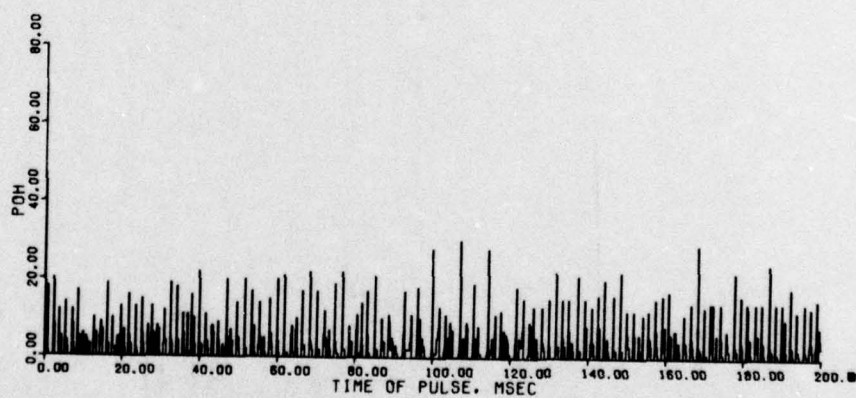
FIGURE   PDH FOR BASSETT.J . 04/05/76.4. 2.

(c)

Figure 39.

(a) The Response of ROC COC's Channel 20 to Stimulus 8B, with a Magnitude of 20 dB Attenuation.

(b) The POH Constructed from the Responses of Neuron 710827/11 (Run 17) to 100 Presentations of the Stimulus in (a).

(c) The POH Constructed from the Responses of Model 04/05/76.4 (Run 3) to 100 Presentations of the Stimulus in (a).
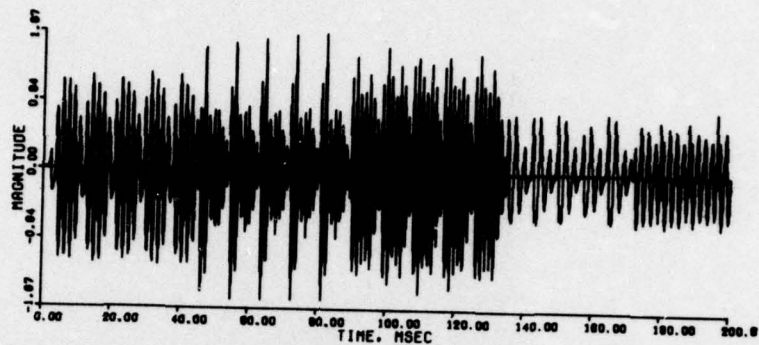
(a)

(b)
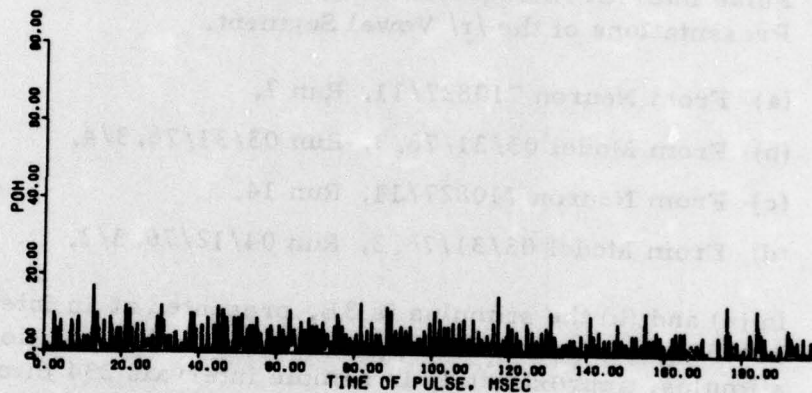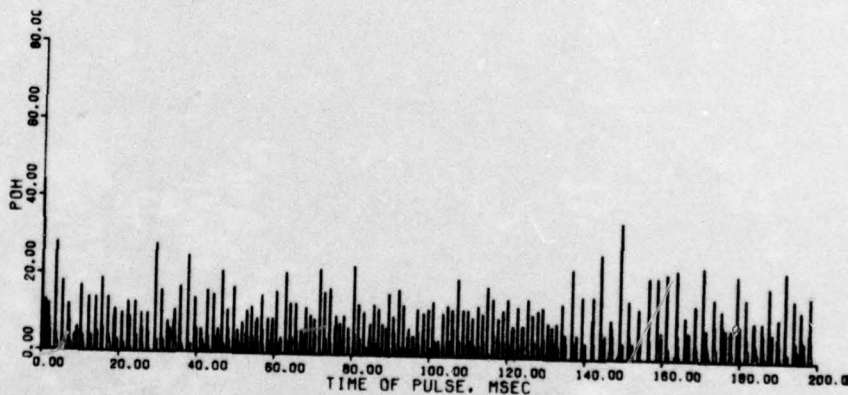
(c)

Figure 40. Pulse Interval Histograms Constructed from Responses to 100 Presentations of the /r/ Vowel Segment.

(a) From Neuron 710827/11, Run 7.

(b) From Model 03/31/76.3, Run 03/31/76.3/4.

(c) From Neuron 710827/11, Run 14.

(d) From Model 03/31/76.3, Run 04/12/76.3/2.

In (a) and (b) the stimulus is 3B, presented at an intensity of 10 dB attenuation. /r/ is located in the second position of this stimulus, approximately in sample intervals 234 through 450. In (c) and (d) the stimulus is 7A, presented at an intensity of 10 dB attenuation. /r/ is located in the third position of this stimulus, approximately in sample intervals 459 through 672.

FIGURE   710627   . 11.. 7.
DEFINING INTERVALS 234 TO 459
AVERAGE = 6.07 NUMBER OF INTERVALS = 572

(a)

FIGURE   BASSETT.J . 03/31/76.3. 4.
DEFINING INTERVALS 234 TO 459
AVERAGE = 6.51 NUMBER OF INTERVALS = 527

(b)

FIGURE   710627   . 11.. 14.
DEFINING INTERVALS 459 TO 672
AVERAGE = 7.34 NUMBER OF INTERVALS = 414

(c)

FIGURE   BASSETT.J . 04/12/76.3. 2.
DEFINING INTERVALS 459 TO 672
AVERAGE = 6.93 NUMBER OF INTERVALS = 472

(d)

97
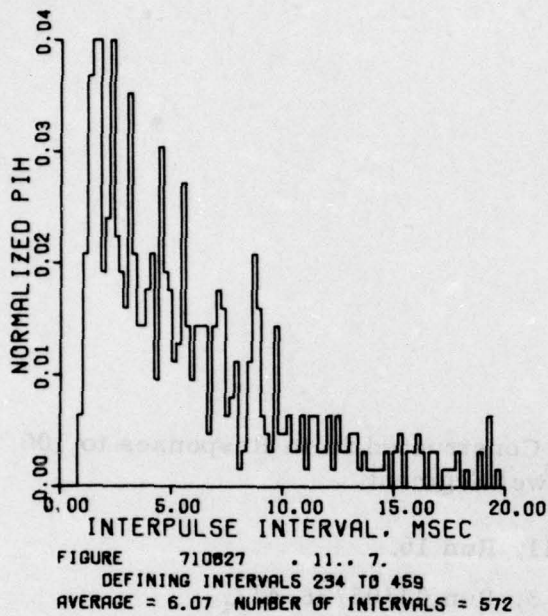
Figure 41.   Pulse Interval Histograms Constructed from Responses to 100
Presentations of the /r̩/ Vowel Segment.

(a) From Neuron 710827/11, Run 16.

(b) From Model 03/31/76.3, Run 04/05/76.4/2.

(c) From Neuron 710827/11, Run 9.

(d) From Model 03/31/76.3, Run 04/12/76.3/1.

In (a) and (b) the stimulus is 8A, presented at an intensity of
20 dB attenuation. /r̩/ is located in the fourth position of this
stimulus, approximately in sample intervals 632 through 862.
In (c) and (d) the stimulus is 4B, presented at an intensity of
40 dB attenuation. /r̩/ is located in the third position of this
stimulus, approximately in sample intervals 368 through 600.

98
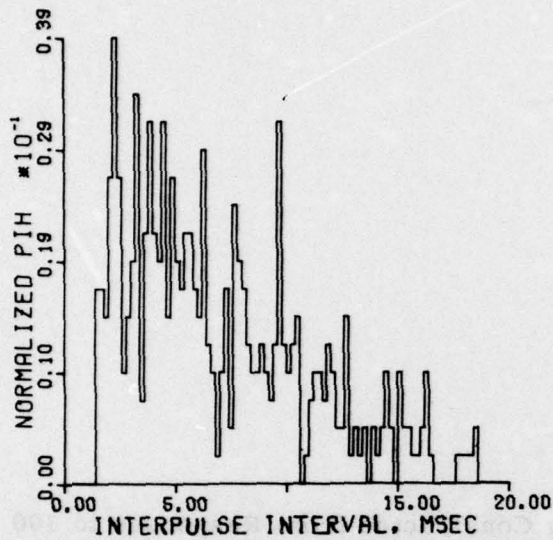
FIGURE   710827   . 11.. 16.
DEFINING INTERVALS 632 TO 862
AVERAGE = 7.34 NUMBER OF INTERVALS = 412

(a)

FIGURE   BASSETT.J . 04/05/76.4. 2.
DEFINING INTERVALS 632 TO 862
AVERAGE = 6.80 NUMBER OF INTERVALS = 527

(b)

FIGURE   710827   . 11.. 9.
DEFINING INTERVALS 368 TO 600
AVERAGE = 4.69 NUMBER OF INTERVALS = 805

(c)

FIGURE   BASSETT.J . 04/12/76.3. 1.
DEFINING INTERVALS 368 TO 600
AVERAGE = 6.78 NUMBER OF INTERVALS = 528

(d)

Figure 42. Pulse Interval Histograms Constructed from Responses to 100
Presentations of the /æ/ Vowel Segment.

(a) From Neuron 710827/11, Run 6.

(b) From Model 03/31/76.3, Run 04/05/76.4/1.

(c) From Neuron 710827/11, Run 15.

(d) From Model 03/32/76.3, Run 04/15/76.3/2.

In (a) and (b) the stimulus is 3A, presented at an intensity of
10 dB attenuation. /æ/ is located in the third position of this
stimulus, approximately in sample intervals 395 through 618.
In (c) and (d) the stimulus is 7B, presented at an intensity of
10 dB attenuation. /æ/ is located in the first position of this
stimulus, approximately in sample intervals 14 through 234.

FIGURE 710827 . 11.. 6.
DEFINING INTERVALS 395 TO 618
AVERAGE = 7.06 NUMBER OF INTERVALS = 425

(a)

FIGURE BASSETT.J . 04/05/76.4. 1.
DEFINING INTERVALS 395 TO 618
AVERAGE = 6.43 NUMBER OF INTERVALS = 534

(b)
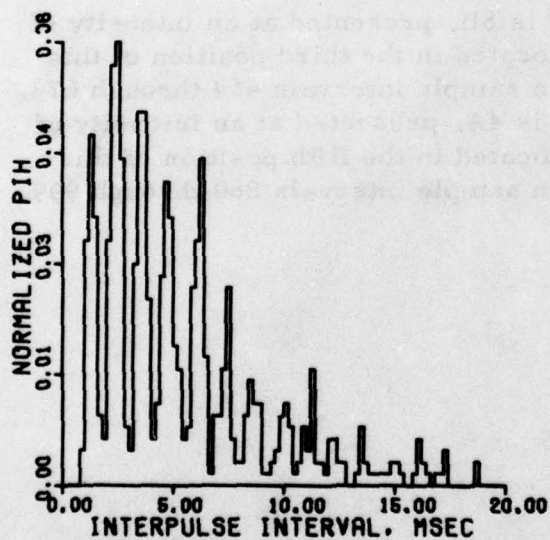
FIGURE 710827 . 11.. 15.
DEFINING INTERVALS 14 TO 234
AVERAGE = 5.46 NUMBER OF INTERVALS = 677

(c)

FIGURE BASSETT.J . 04/15/76.3. 2.
DEFINING INTERVALS 14 TO 234
AVERAGE = 5.47 NUMBER OF INTERVALS = 510

(d)

101

Figure 43.   Pulse Interval Histograms Constructed from Responses to 100
Presentations of the /æ/ Vowel Segment.

(a) From Neuron 710827/11, Run 17.

(b) From Model 03/31/76. 3, Run 04/05/76. 3/1.

(c) From Neuron 710827/11, Run 8.

(d) From Model 03/31/76. 3, Run 04/15/76. 3/1.

In (a) and (b) the stimulus is 8B, presented at an intensity of
20 dB attenuation. /æ/ is located in the third position of this
stimulus, approximately in sample intervals 454 through 674.
In (c) and (d) the stimulus is 4A, presented at an intensity of
40 dB attenuation. /æ/ is located in the fifth position of this
stimulus, approximately in sample intervals 880 through 999.

FIGURE 710827 . 11. 17.
DEFINING INTERVALS 454 TO 674
AVERAGE = 7.41 NUMBER OF INTERVALS = 424

(a)

FIGURE BASSETT.J . 04/05/76.4. 9.
DEFINING INTERVALS 454 TO 674
AVERAGE = 6.48 NUMBER OF INTERVALS = 509

(b)
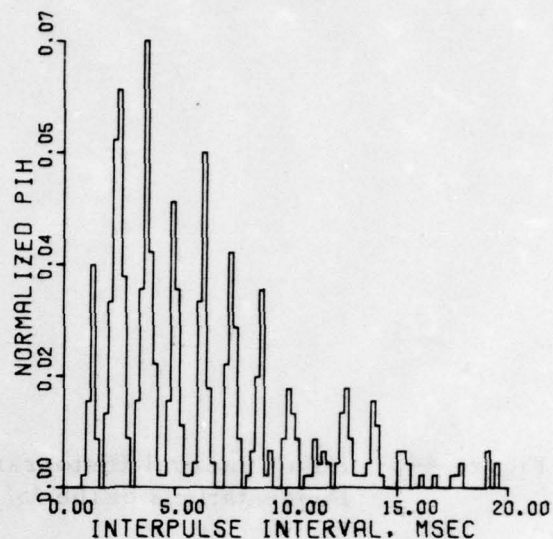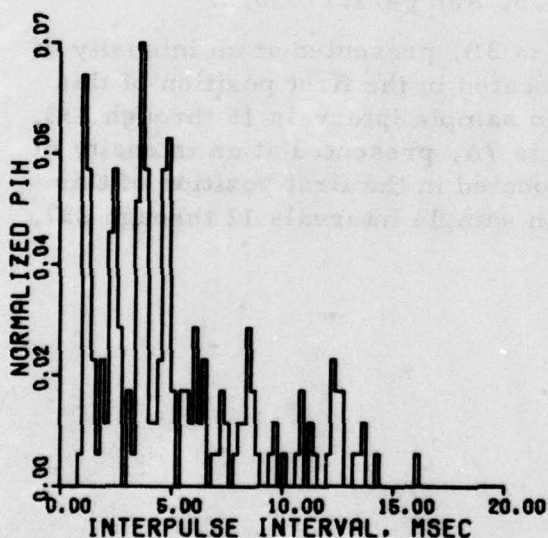
FIGURE 710827 . 11. 9.
DEFINING INTERVALS 860 TO 999
AVERAGE = 5.29 NUMBER OF INTERVALS = 195

FIGURE BASSETT.J . 04/15/76.3. 1.
DEFINING INTERVALS 860 TO 999
AVERAGE = 5.66 NUMBER OF INTERVALS = 208

(d)

103
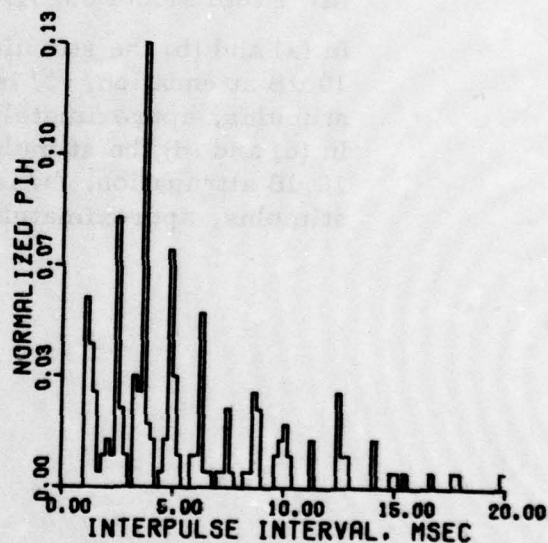
Figure 44.   Pulse Interval Histograms Constructed from Responses to 100
Presentations of the /ɔ/ Vowel Segment.

(a) From Neuron 710827/11, Run 7.

(b) From Model 03/31/76.3, Run 03/31/76.3/4.

(c) From Neuron 710827/11, Run 14.

(d) From Model 03/31/76.3, Run 04/12/76.3/2.

In (a) and (b) the stimulus is 3B, presented at an intensity of
10 dB attenuation. /ɔ/ is located in the first position of this
stimulus, approximately in sample intervals 15 through 233.
In (c) and (d) the stimulus is 7A, presented at an intensity of
10 dB attenuation. /ɔ/ is located in the first position of this
stimulus, approximately in sample intervals 12 through 237.
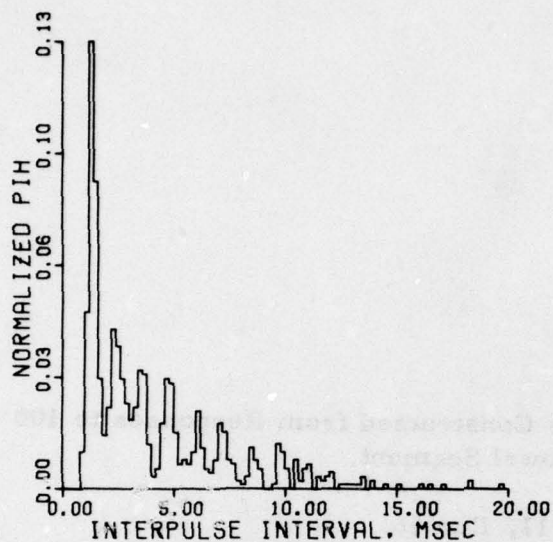
FIGURE   710827   .11.. 7.
DEFINING INTERVALS 15 TO 233
AVERAGE = 4.38   NUMBER OF INTERVALS = 842
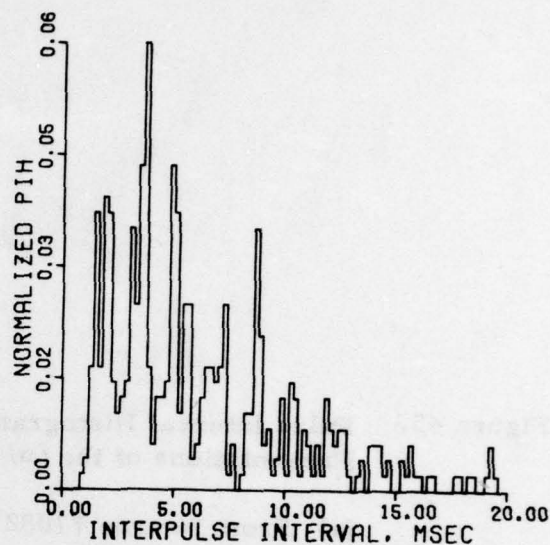
(a)

FIGURE   BASSETT.J . 03/31/76.3. 4.
DEFINING INTERVALS 15 TO 233
AVERAGE = 6.63   NUMBER OF INTERVALS = 481

(b)
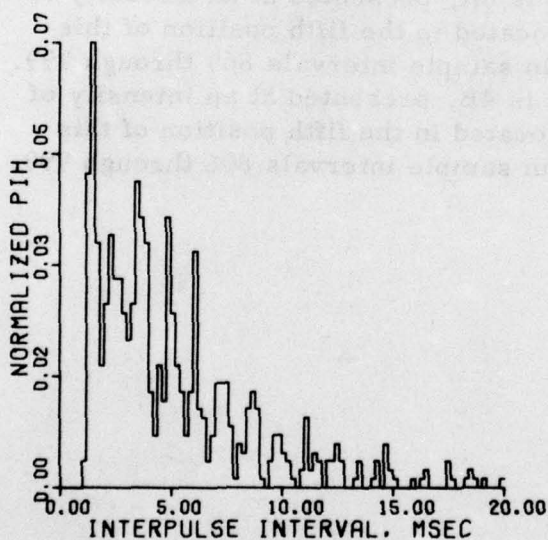
FIGURE   710827   .11.. 14.
DEFINING INTERVALS 12 TO 237
AVERAGE = 5.23   NUMBER OF INTERVALS = 742

(c)
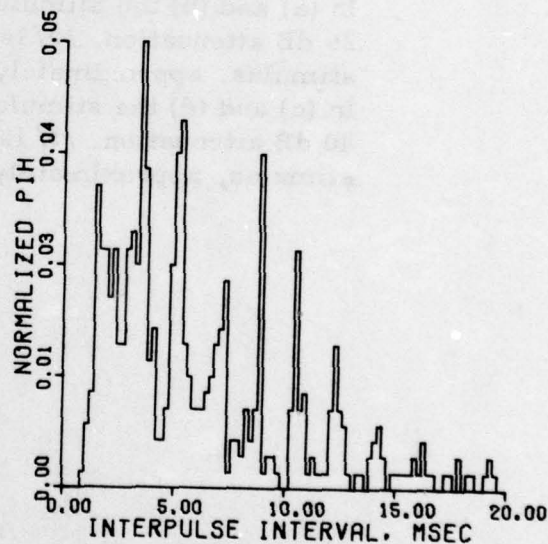
FIGURE   BASSETT.J . 04/12/76.3. 2.
DEFINING INTERVALS 12 TO 237
AVERAGE = 6.60   NUMBER OF INTERVALS = 519

(d)

105

Figure 45. Pulse Interval Histograms Constructed from Responses to 100 Presentations of the /ɔ/ Vowel Segment.

(a) From Neuron 710827/11, Run 16.

(b) From Model 03/31/76.3, Run 04/05/76.4/2.

(c) From Neuron 701827/11, Run 9.

(d) From Model 03/31/76.3, Run 04/12/76.3/1.

In (a) and (b) the stimulus is 8A, presented at an intensity of 20 dB attenuation. /ɔ/ is located in the fifth position of this stimulus, approximately in sample intervals 869 through 999. In (c) and (d) the stimulus is 4B, presented at an intensity of 40 dB attenuation. /ɔ/ is located in the fifth position of this stimulus, approximately in sample intervals 806 through 999.

FIGURE 710827 . 11.. 16.
DEFINING INTERVALS 863 TO 999
AVERAGE = 7.11   NUMBER OF INTERVALS = 200

(a)

FIGURE BASSETT.J . 04/05/76.4. 2.
DEFINING INTERVALS 863 TO 999
AVERAGE = 6.26   NUMBER OF INTERVALS = 256

(b)

FIGURE 710827 . 11.. 9.
DEFINING INTERVALS 806 TO 999
AVERAGE = 9.10   NUMBER OF INTERVALS = 133

(c)

FIGURE BASSETT.J . 04/12/76.3. 1.
DEFINING INTERVALS 806 TO 999
AVERAGE = 7.26   NUMBER OF INTERVALS = 407

(c)

107
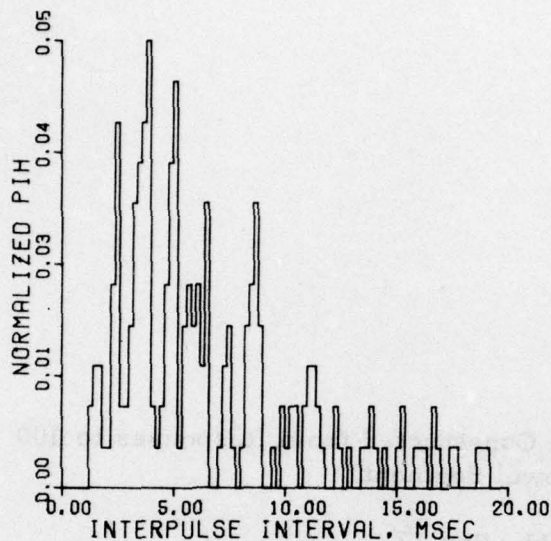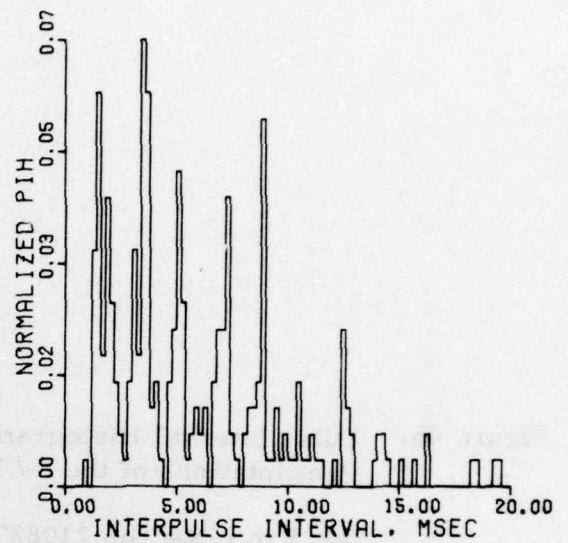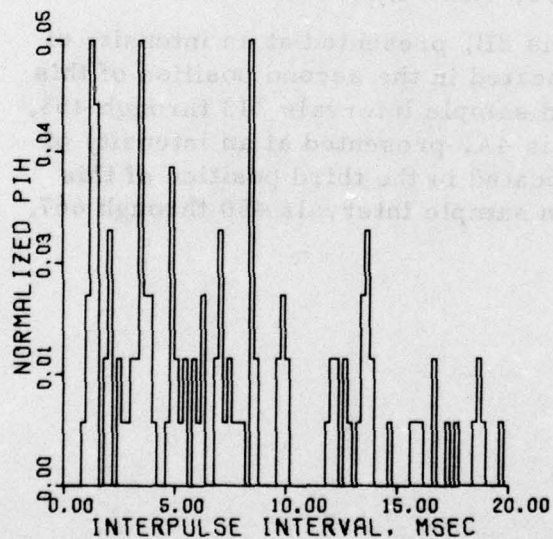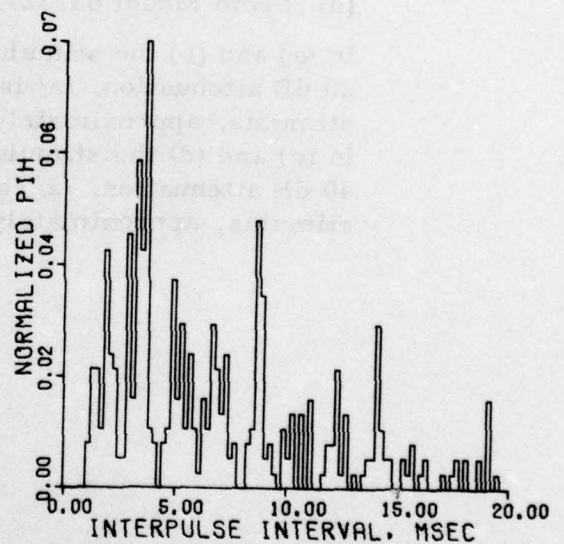
Figure 46. Pulse Interval Histograms Constructed from Responses to 100 Presentations of the /a/ Vowel Segment.

(a) From Neuron 710827/11, Run 17.

(b) From Model 03/31/76.3, Run 04/05/76.4/3.

(c) From Neuron 710827/11, Run 8.

(d) From Model 03/32/76.3, Run 04/15/76.3/1.

In (a) and (b) the stimulus is 8B, presented at an intensity of 20 dB attenuation. /a/ is located in the second position of this stimulus, approximately in sample intervals 213 through 453. In (c) and (d) the stimulus is 4A, presented at an intensity of 40 dB attenuation. /a/ is located in the third position of this stimulus, approximately in sample intervals 450 through 667.
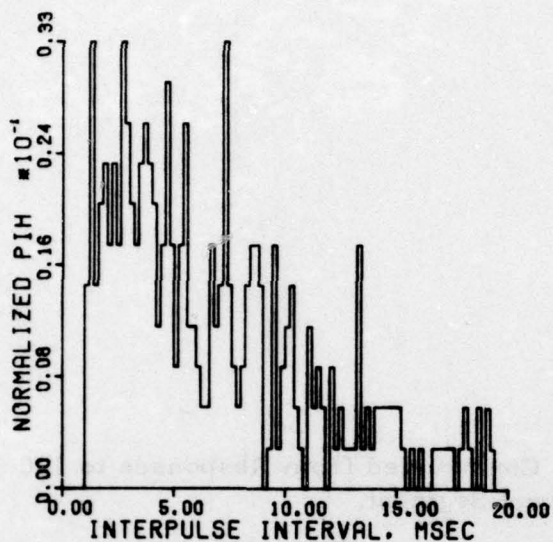
FIGURE   710627   . 11.. 6.
DEFINING INTERVALS 619 TO 640
AVERAGE = 7.61   NUMBER OF INTERVALS = 338

(a)
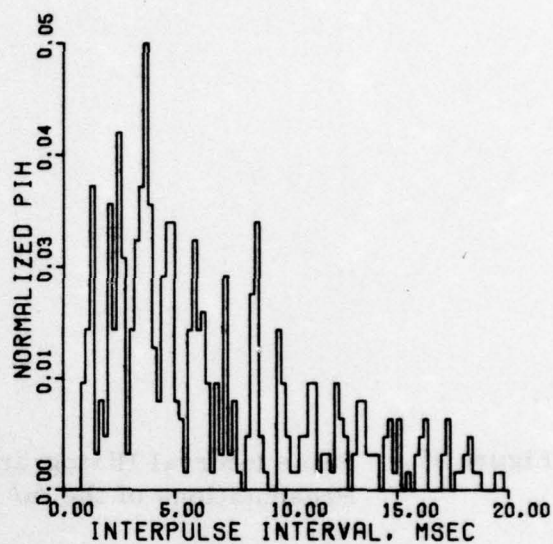
FIGURE   BASSETT.J . 04/05/76. 4. 1.
DEFINING INTERVALS 619 TO 640
AVERAGE = 6.94   NUMBER OF INTERVALS = 461

(b)
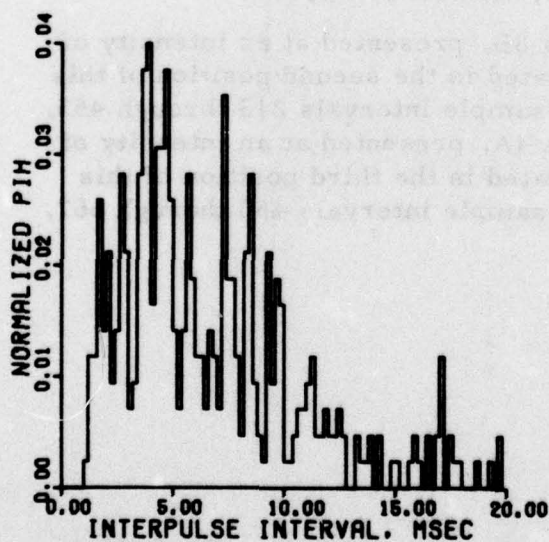
FIGURE   710627   . 11.. 15.
DEFINING INTERVALS 450 TO 667
AVERAGE = 7.45   NUMBER OF INTERVALS = 419

(c)
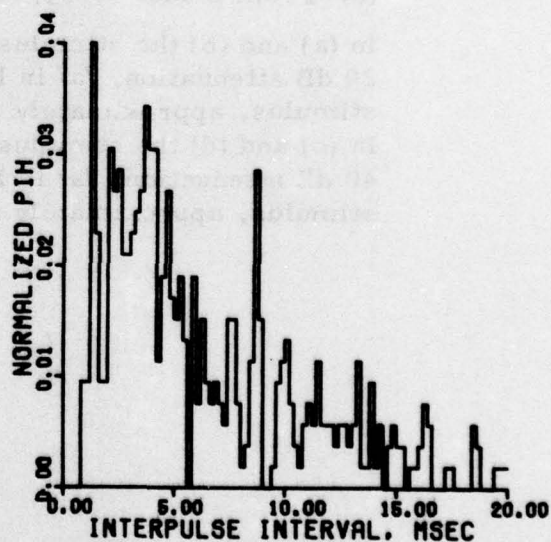
FIGURE   BASSETT.J . 04/15/76. 3. 2.
DEFINING INTERVALS 450 TO 667
AVERAGE = 6.61   NUMBER OF INTERVALS = 455

(d)

Figure 47.   Pulse Interval Histograms Constructed from Responses to 100
              Presentations of the /a/ Vowel Segment.

(a) From Neuron 710827/11, Run 17.

(b) From Model 03/31/76.3, Run 04/05/76.4/3.

(c) From Neuron 710827/11, Run 8.

(d) From Model 03/31/76.3, Run 04/15/76.3/1.

In (a) and (b) the stimulus is 8B, presented at an intensity of
20 dB attenuation. /a/ is located in the second position of this
stimulus, approximately in sample intervals 213 through 453.
In (c) and (d) the stimulus is 4A, presented at an intensity of
40 dB attenuation. /a/ is located in the third position of this
stimulus, approximately in sample intervals 450 thorugh 667.

110

FIGURE   710827   . 11.. 17.
DEFINING INTERVALS 213 TO 453
AVERAGE = 6.66   NUMBER OF INTERVALS = 561

(a)

FIGURE   BASSETT.J . 04/05/76.4. 9.
DEFINING INTERVALS 213 TO 453
AVERAGE = 6.68   NUMBER OF INTERVALS = 562

(b)

FIGURE   710827   . 11.. 9.
DEFINING INTERVALS 480 TO 667
AVERAGE = 6.16   NUMBER OF INTERVALS = 478

(c)

FIGURE   BASSETT.J . 04/15/76.3. 1.
DEFINING INTERVALS 480 TO 667
AVERAGE = 6.65   NUMBER OF INTERVALS = 480

(d)

111

Figure 48.   Pulse Interval Histograms Constructed from Responses to 100
Presentations of the /I/ Vowel Segment.

(a)   From Neuron 710827/11, Run 6.

(b)   From Model 03/31/76.3, Run 04/05/76.4/1.

(c)   From Neuron 710827/11, Run 14.

(d)   From Model 03/31/76.3, Run 04/12/76.3/2.

In (a) and (b) the stimulus is 3A, presented at an intensity of
10 dB attenuation. /I/ is located in the first position of this
stimulus, approximately in sample intervals 14 through 215.
In (c) and (d) the stimulus is 7A, presented at an intensity of
10 dB attenuation. /I/ is located in the second position of this
stimulus, approximately in sample intervals 238 through 458.

112
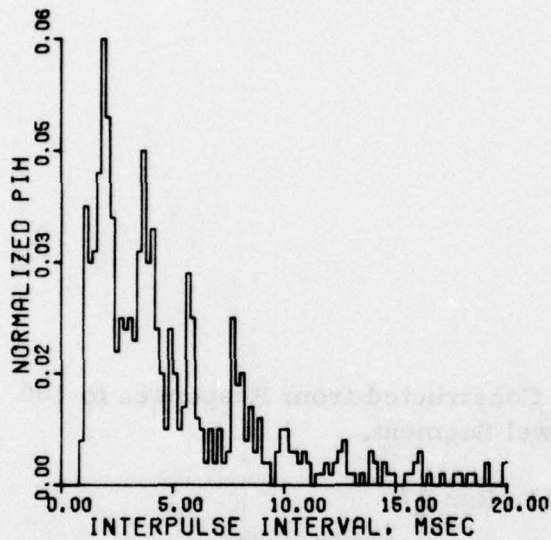
FIGURE   710827   . 11.. 5.
DEFINING INTERVALS 14 TO 215
AVERAGE = 5.06   NUMBER OF INTERVALS = 617

(a)
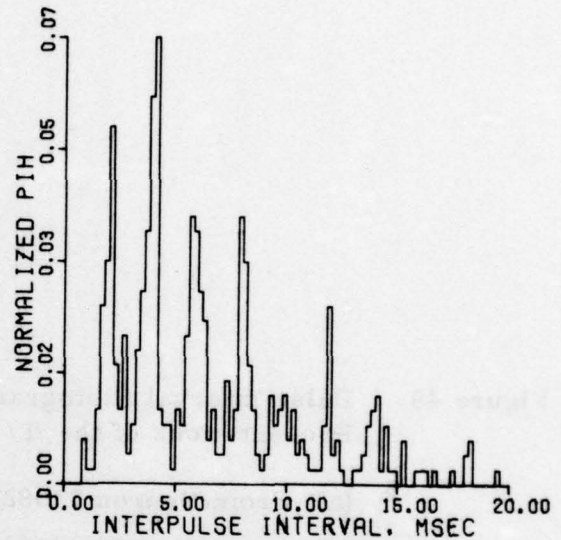
FIGURE   BASSETT.J . 04/05/76.4. 1.
DEFINING INTERVALS 14 TO 215
AVERAGE = 6.64   NUMBER OF INTERVALS = 459

(b)
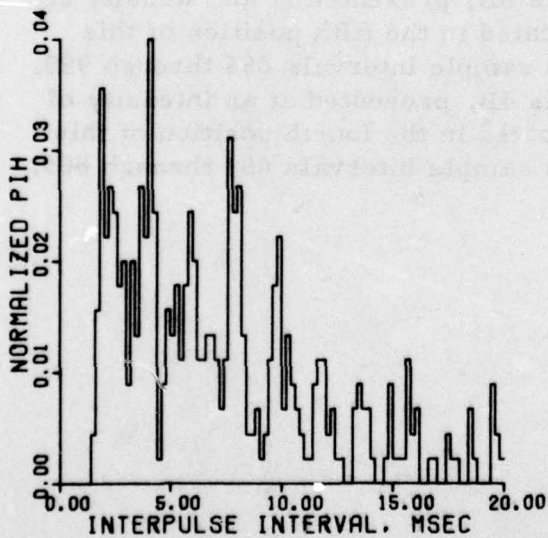
FIGURE   710827   . 11.. 14.
DEFINING INTERVALS 236 TO 456
AVERAGE = 7.59   NUMBER OF INTERVALS = 413

(c)
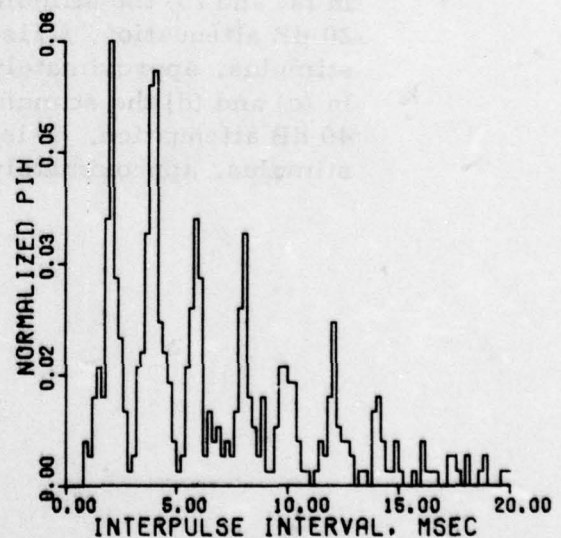
FIGURE   BASSETT.J . 04/12/76.3. 2.
DEFINING INTERVALS 236 TO 456
AVERAGE = 6.90   NUMBER OF INTERVALS = 476

(d)

Figure 49.   Pulse Interval Histograms Constructed from Responses to 100
             Presentations of the /I/ Vowel Segment.

(a) From Neuron 710827/11, Run 17.

(b) From Model 03/31/76.3, Run 04/05/76.4/3.

(c) From Neuron 710827/11, Run 9.

(d) From Model 03/31/76.3, Run 04/12/76.3/1.

In (a) and (b) the stimulus is 8B, presented at an intensity of
20 dB attenuation. /I/ is located in the fifth position of this
stimulus, approximately in sample intervals 854 through 999.
In (c) and (d) the stimulus is 4B, presented at an intensity of
40 dB attenuation. /I/ is located in the fourth position of this
stimulus, approximately in sample intervals 601 through 805.
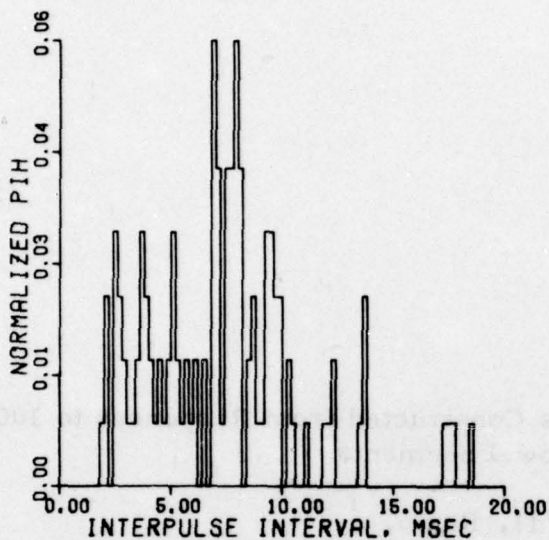
FIGURE   710827   . 11.. 17.
DEFINING INTERVALS 854 TO 999
AVERAGE = 7.52   NUMBER OF INTERVALS = 119

(a)
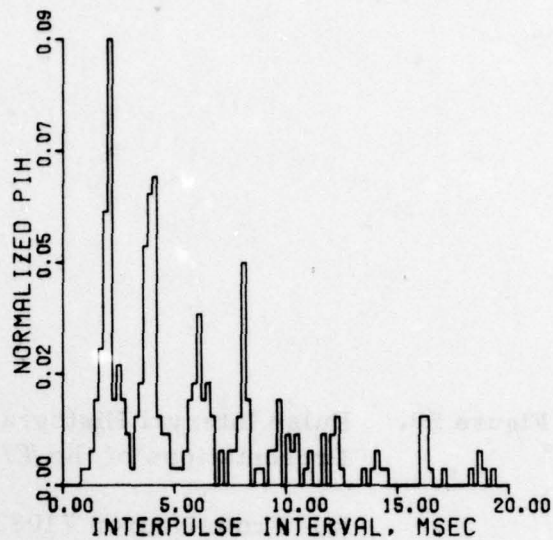
FIGURE   BASSETT.J . 04/05/76.4. 3.
DEFINING INTERVALS 854 TO 999
AVERAGE = 6.32   NUMBER OF INTERVALS = 278

(b)
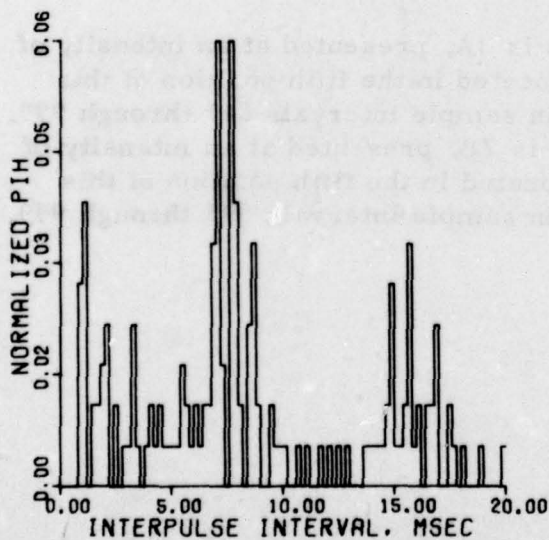
FIGURE   710827   . 11.. 9.
DEFINING INTERVALS 601 TO 805
AVERAGE = 10.39   NUMBER OF INTERVALS = 177

(c)
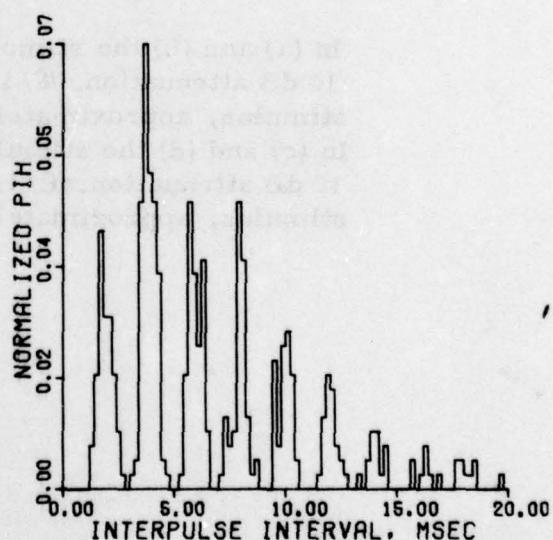
FIGURE   BASSETT.J . 04/12/76.3. 1.
DEFINING INTERVALS 601 TO 805
AVERAGE = 7.06   NUMBER OF INTERVALS = 424

(d)

115

Figure 50. Pulse Interval Histograms Constructed from Responses to 100 Presentations of the /ℰ/ Vowel Segment.

(a) From Neuron 710827/11, Run 6.

(b) From Model 03/31/76.3, Run 04/05/76.4/1.

(c) From Neuron 710827/11, Run 15.

(d) From Model 03/31/76.3, Run 04/15/76.3/2.

In (a) and (b) the stimulus is 3A, presented at an intensity of 10 dB attenuation. /ℰ/ is located in the fifth position of this stimulus, approximately in sample intervals 841 through 999. In (c) and (d) the stimulus is 7B, presented at an intensity of 10 dB attenuation. /ℰ/ is located in the fifth position of this stimulus, approximately in sample intervals 895 through 999.

116
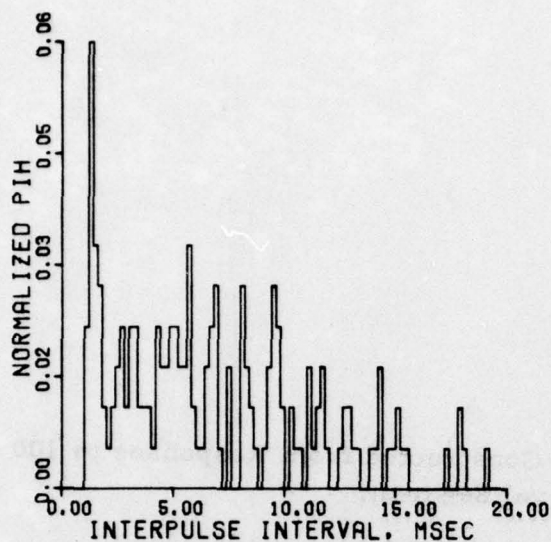
FIGURE   710827   . 11.. 6.
DEFINING INTERVALS 641 TO 999
AVERAGE = 7.26   NUMBER OF INTERVALS = 172

(a)
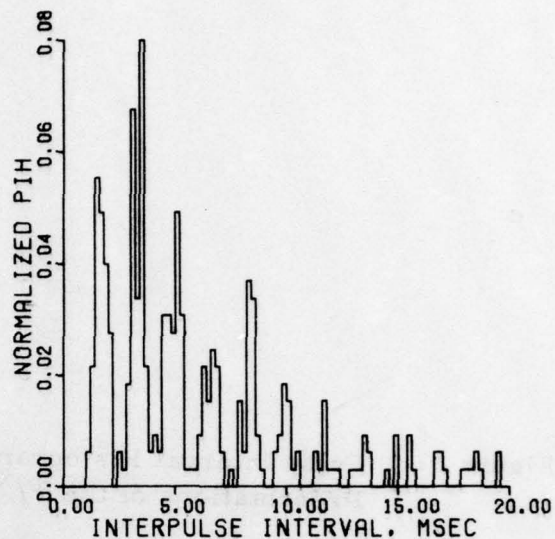
FIGURE   BASSETT.J . 04/05/76.4. 1.
DEFINING INTERVALS 641 TO 999
AVERAGE = 6.23   NUMBER OF INTERVALS = 336

(b)
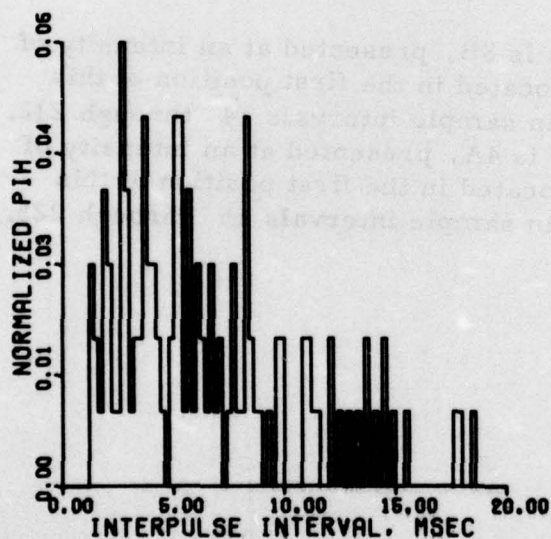
FIGURE   710827   . 11.. 15.
DEFINING INTERVALS 695 TO 999
AVERAGE = 6.91   NUMBER OF INTERVALS = 115

(c)
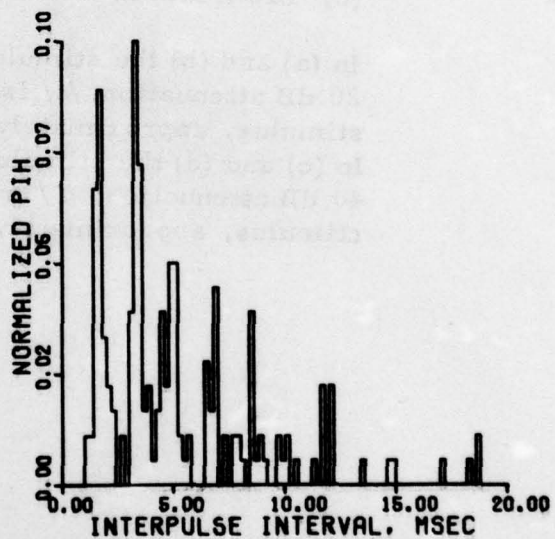
FIGURE   BASSETT.J . 04/15/76.3. 2.
DEFINING INTERVALS 695 TO 999
AVERAGE = 5.26   NUMBER OF INTERVALS = 166

(d)

117

Figure 51.   Pulse Interval Histograms Constructed from Responses to 100
Presentations of the /ε/ Vowel Segment.

(a)   From Neuron 710827/11, Run 17.

(b)   From Model 03/31/76.3, Run 04/05/76.4/3.

(c)   From Neuron 710827/11, Run 8.

(d)   From Model 03/31/76.3, Run 04/15/76.3/1.

In (a) and (b) the stimulus is 8B, presented at an intensity of
20 dB attenuation. /ε/ is located in the first position of this
stimulus, approximately in sample intervals 14 through 212.
In (c) and (d) the stimulus is 4A, presented at an intensity of
40 dB attenuation. /ε/ is located in the first position of this
stimulus, approximately in sample intervals 15 through 225.

118
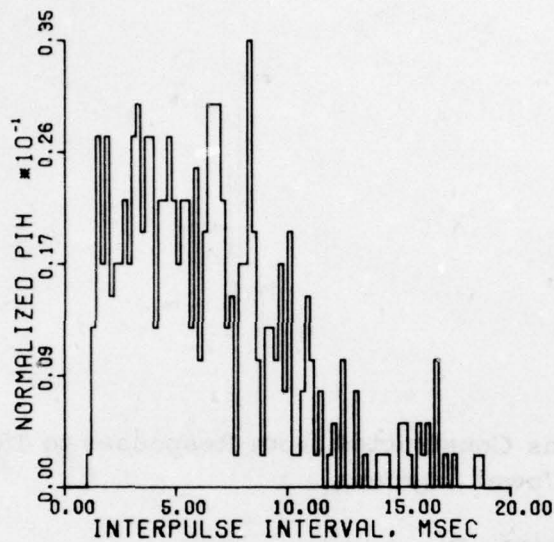
FIGURE   710827 . 11.. 17.
DEFINING INTERVALS 14 TO 212
AVERAGE = 6.70 NUMBER OF INTERVALS = 405

(a)
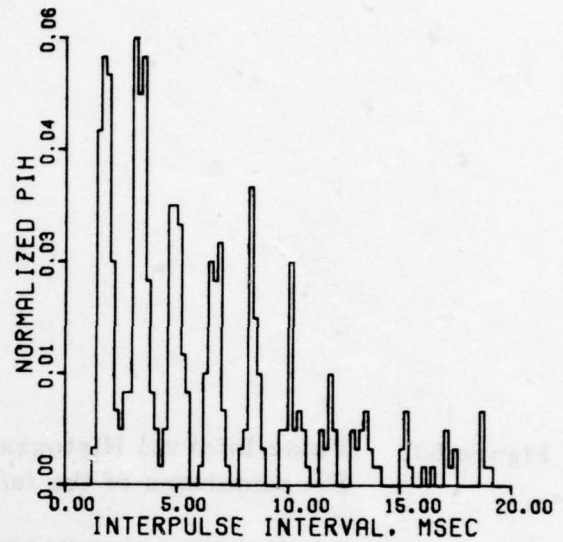
FIGURE   BASSETT.J . 04/05/76.4. 3.
DEFINING INTERVALS 14 TO 212
AVERAGE = 6.64 NUMBER OF INTERVALS = 423

(b)
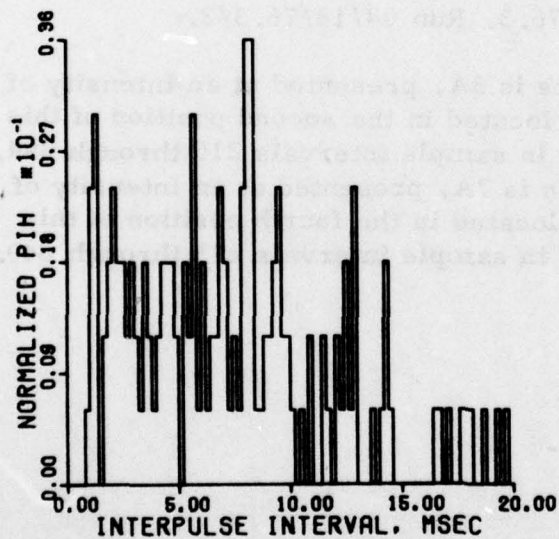
FIGURE   710827 . 11.. 8.
DEFINING INTERVALS 15 TO 225
AVERAGE = 9.62 NUMBER OF INTERVALS = 157

(c)
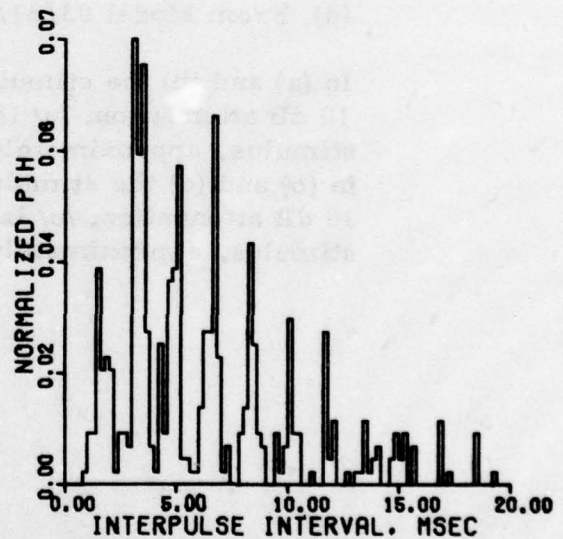
FIGURE   BASSETT.J . 04/15/76.3. 1.
DEFINING INTERVALS 14 TO 225
AVERAGE = 6.55 NUMBER OF INTERVALS = 471

(d)

119

Figure 52. Pulse Interval Histograms Constructed from Responses to 100
Presentations of the /u/ Vowel Segment.

(a) From Neuron 710827/11, Run 6.

(b) From Model 03/31/76.3, Run 04/05/76.4/1.

(c) From Neuron 710827/11, Run 14.

(d) From Model 03/31/76.3, Run 04/12/76.3/2.

In (a) and (b) the stimulus is 3A, presented at an intensity of
10 dB attenuation. /u/ is located in the second position of this
stimulus, approximately in sample intervals 216 through 394.
In (c) and (d) the stimulus is 7A, presented at an intensity of
10 dB attenuation. /u/ is located in the fourth position of this
stimulus, approximately in sample intervals 673 through 849.
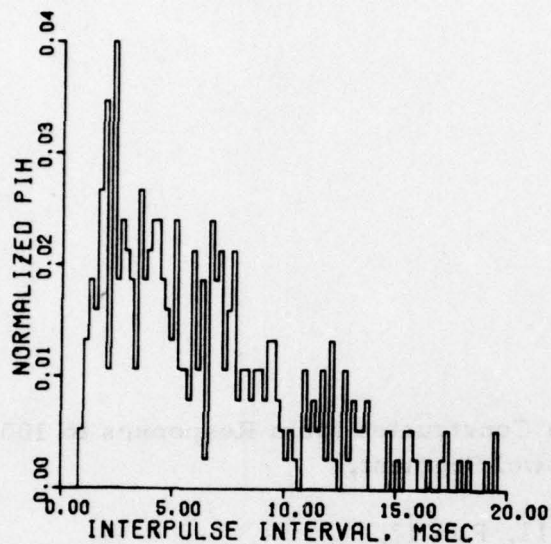
FIGURE 710827 . 11.. 6.
DEFINING INTERVALS 216 TO 394
AVERAGE = 6.61   NUMBER OF INTERVALS = 343

(a)
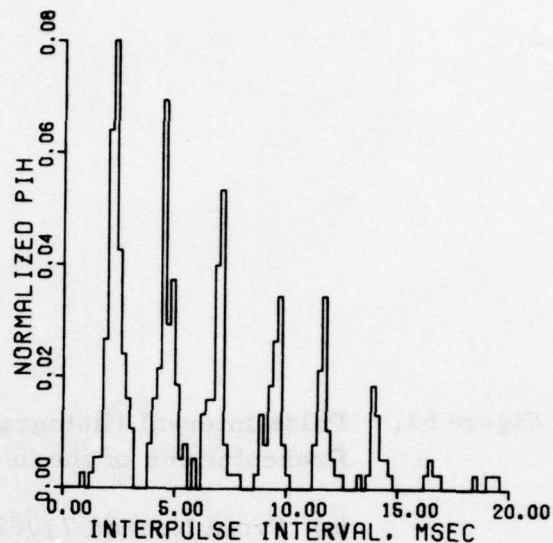
FIGURE BASSETT.J . 04/05/76.4. 1.
DEFINING INTERVALS 216 TO 394
AVERAGE = 6.91   NUMBER OF INTERVALS = 357

(b)
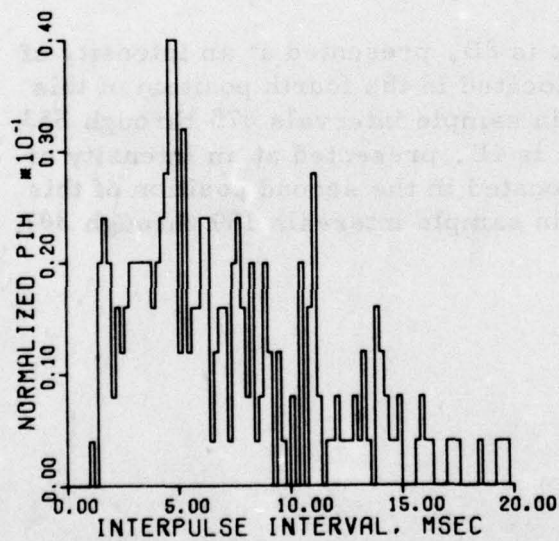
FIGURE 710827 . 11.. 14.
DEFINING INTERVALS 673 TO 849
AVERAGE = 7.84   NUMBER OF INTERVALS = 250

(c)
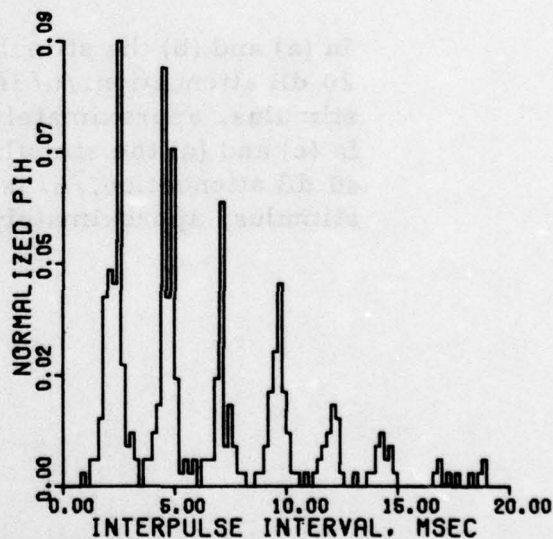
FIGURE BASSETT.J . 04/12/76.3. 2.
DEFINING INTERVALS 673 TO 849
AVERAGE = 6.53   NUMBER OF INTERVALS = 355

(d)

121

Figure 53.   Pulse Interval Histograms Constructed from Responses to 100
Presentations of the /u/ Vowel Segment.

(a)   From Neuron 710827/11, Run 17.

(b)   From Model 03/31/76.3, Run 04/05/76.4/3.

(c)   From Neuron 710827/11, Run 9.

(d)   From Model 03/31/76.3, Run 04/12/76.3/1.

In (a) and (b) the stimulus is 8B, presented at an intensity of
20 dB attenuation. /u/ is located in the fourth position of this
stimulus, approximately in sample intervals 675 through 853.
In (c) and (d) the stimulus is 4B, presented at an intensity of
40 dB attenuation. /u/ is located in the second position of this
stimulus, approximately in sample intervals 189 through 367.
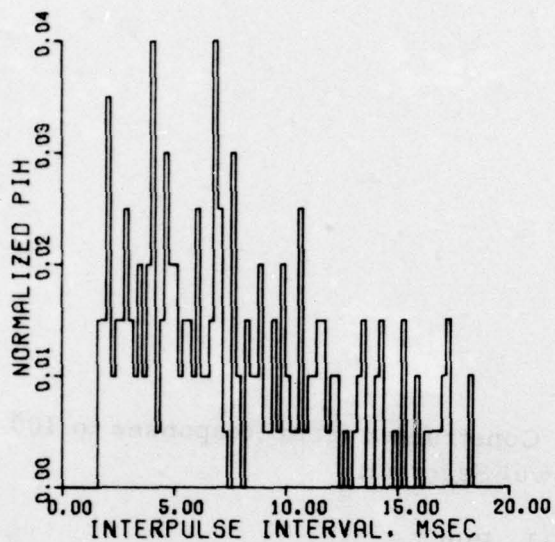
FIGURE   710827   . 11.. 17.
DEFINING INTERVALS 675 TO 853
AVERAGE = 8.75   NUMBER OF INTERVALS = 197

(a)
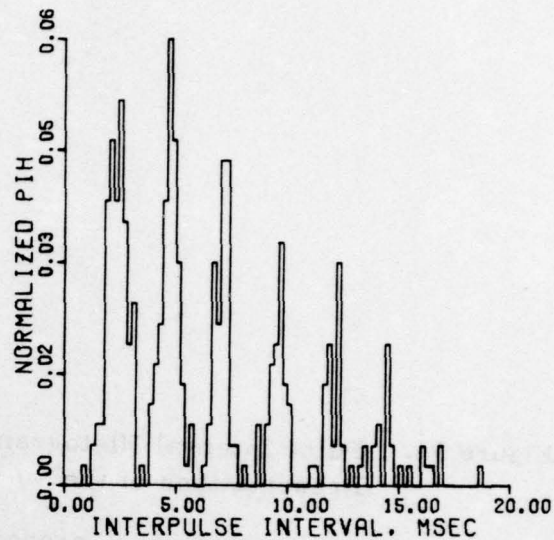
FIGURE   BASSETT.J . 04/05/76.4. 3.
DEFINING INTERVALS 675 TO 853
AVERAGE = 6.85   NUMBER OF INTERVALS = 359

(b)
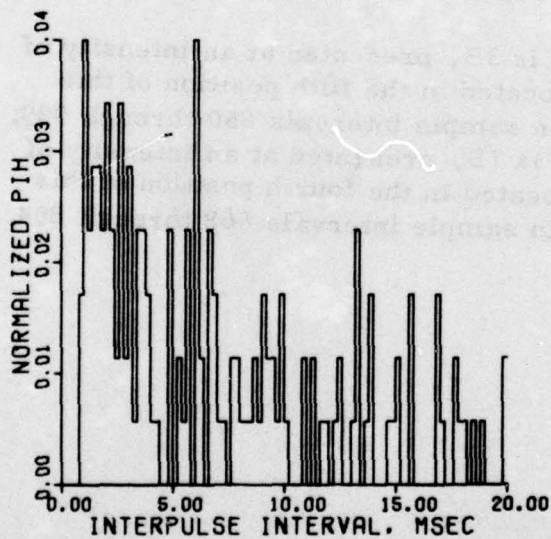
FIGURE   710827   . 11.. 9.
DEFINING INTERVALS 189 TO 367
AVERAGE = 8.37   NUMBER OF INTERVALS = 168

(c)
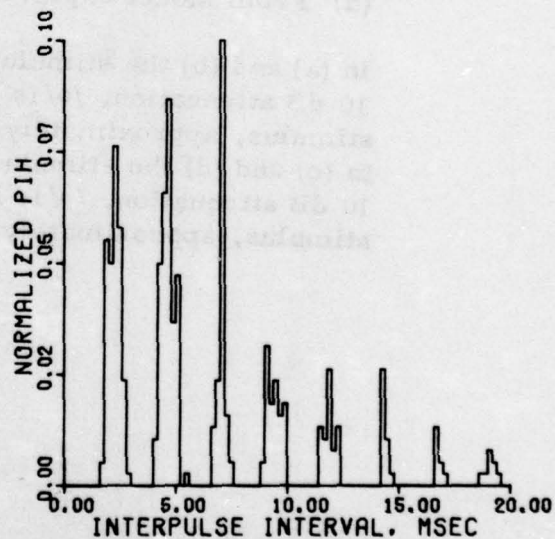
FIGURE   BASSETT.J . 04/12/76.3. 1.
DEFINING INTERVALS 189 TO 367
AVERAGE = 6.78   NUMBER OF INTERVALS = 365

(d)

123

Figure 54. **Pulse Interval Histograms Constructed from Responses to 100 Presentations of the /ə/ Vowel Segment.**

(a) From Neuron 710827/11, Run 7.

(b) From Model 03/31/76.3, Run 03/31/76.3/4.

(c) From Neuron 710827/11, Run 15.

(d) From Model 03/31/76.3, Run 04/15/76.3/2.

In (a) and (b) the stimulus is 3B, presented at an intensity of 10 dB attenuation. /ə/ is located in the fifth position of this stimulus, approximately in sample intervals 850 through 999. In (c) and (d) the stimulus is 7B, presented at an intensity of 10 dB attenuation. /ə/ is located in the fourth position of this stimulus, approximately in sample intervals 668 through 894.

124
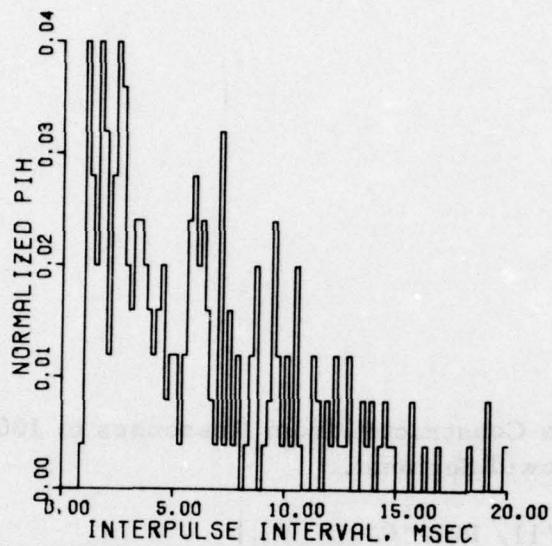
FIGURE   710827   . 11.. 7.
DEFINING INTERVALS 850 TO 999
AVERAGE = 6.49   NUMBER OF INTERVALS = 243

(a)
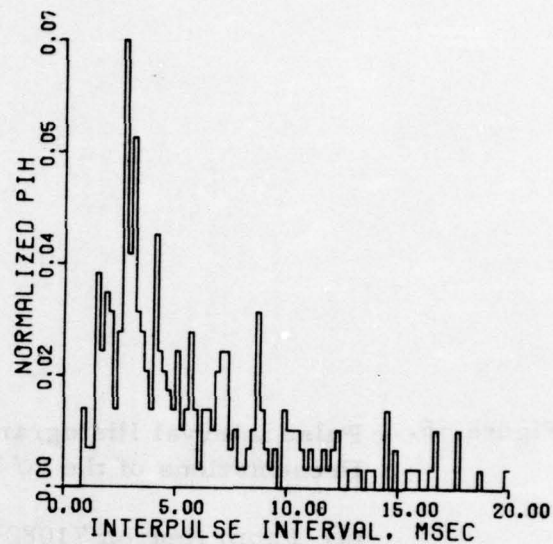
FIGURE   BASSETT.J . 03/31/76.3. 4.
DEFINING INTERVALS 850 TO 999
AVERAGE = 6.11   NUMBER OF INTERVALS = 316

(b)
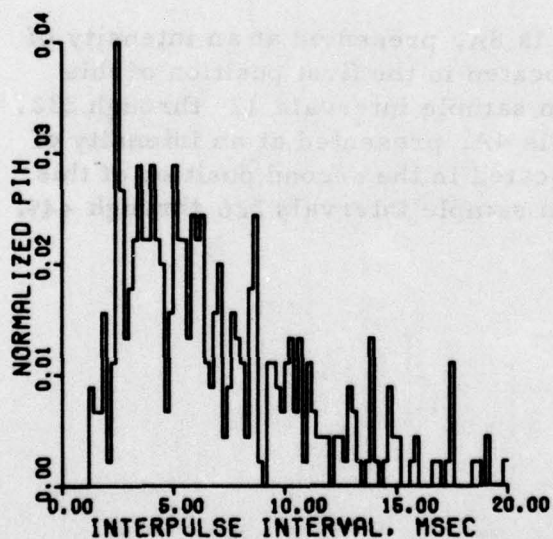
FIGURE   710827   . 11.. 15.
DEFINING INTERVALS 668 TO 694
AVERAGE = 7.62   NUMBER OF INTERVALS = 409

(c)
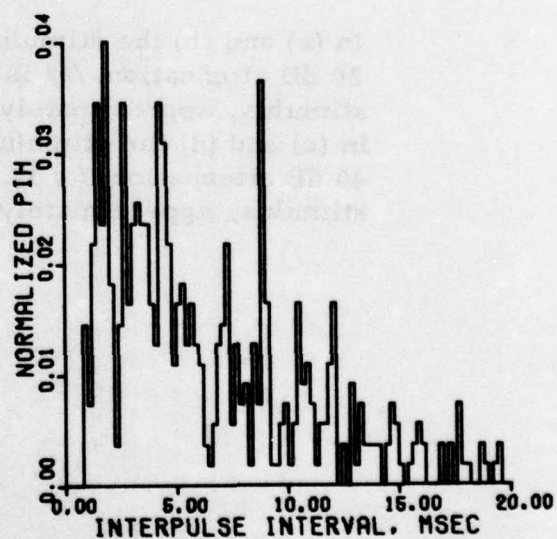
FIGURE   BASSETT.J . 04/15/76.3. 2.
DEFINING INTERVALS 668 TO 694
AVERAGE = 6.76   NUMBER OF INTERVALS = 512

(d)

125

Figure 55.   Pulse Interval Histograms Constructed from Responses to 100
               Presentations of the /ə/ Vowel Segment.

               (a)   From Neuron 710827/11, Run 16.

               (b)   From Model 03/31/76.3, Run 04/05/76.4/2.

               (c)   From Neuron 710827/11, Run 8.

               (d)   From Model 03/31/76.3, Run 04/15/76.3/1.

               In (a) and (b) the stimulus is 8A, presented at an intensity of
               20 dB attenuation. /ə/ is located in the first position of this
               stimulus, approximately in sample intervals 12 through 232.
               In (c) and (d) the stimulus is 4A, presented at an intensity of
               40 dB attenuation. /ə/ is located in the second position of this
               stimulus, approximately in sample intervals 226 through 449.
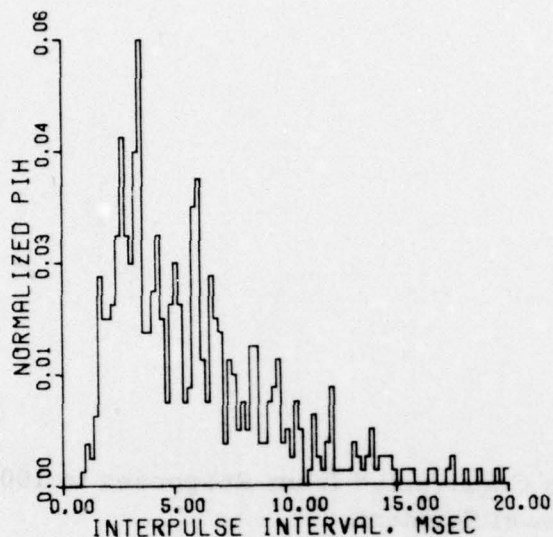
FIGURE   710827   . 11.. 16.
DEFINING INTERVALS 12 TO 232
AVERAGE = 6.18 NUMBER OF INTERVALS = 581

(a)
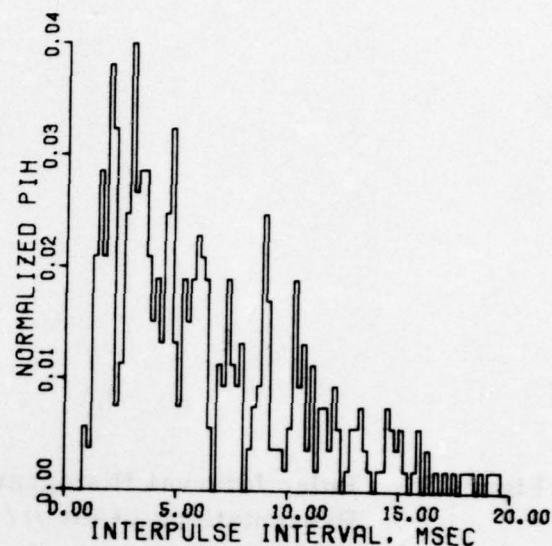
FIGURE   BASSETT.J . 04/05/76.4. 2.
DEFINING INTERVALS 12 TO 232
AVERAGE = 6.71 NUMBER OF INTERVALS = 496

(b)
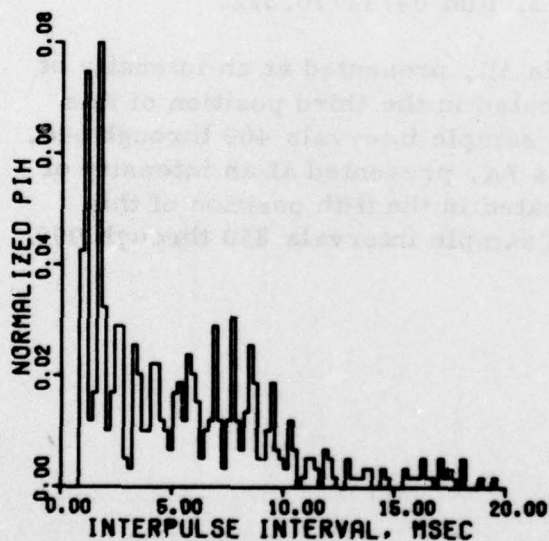
FIGURE   710827   . 11.. 8.
DEFINING INTERVALS 226 TO 449
AVERAGE = 5.63 NUMBER OF INTERVALS = 557

(c)
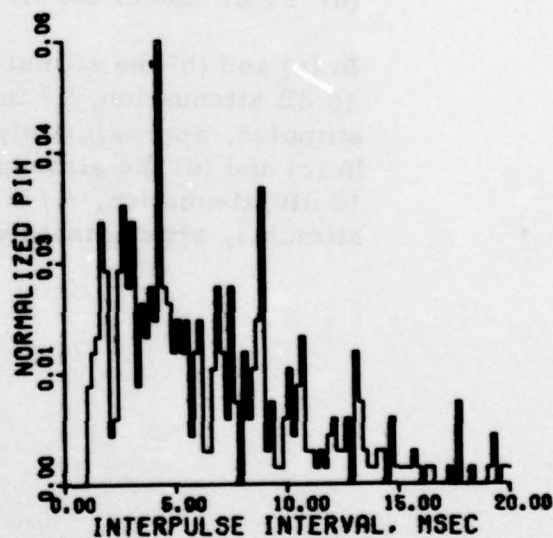
FIGURE   BASSETT.J . 04/15/76.3. 1.
DEFINING INTERVALS 226 TO 449
AVERAGE = 6.65 NUMBER OF INTERVALS = 486

(d)

Figure 56.   Pulse Interval Histograms Constructed from Responses to 100
             Presentations of the /i/ Vowel Segment.

(a) From Neuron 710827/11, Run 7.

(b) From Model 03/31/76.3, Run 03/31/76.3/4.

(c) From Neuron 710827/11, Run 14.

(d) From Model 03/31/76.3, Run 04/12/76.3/2.

In (a) and (b) the stimulus is 3B, presented at an intensity of
10 dB attenuation. /i/ is located in the third position of this
stimulus, approximately in sample intervals 460 through 640.
In (c) and (d) the stimulus is 7A, presented at an intensity of
10 dB attenuation. /i/ is located in the fifth position of this
stimulus, approximately in sample intervals 850 through 999.

128

FIGURE   710627   . 11.. 7.
DEFINING INTERVALS 460 TO 640
AVERAGE = 6.46   NUMBER OF INTERVALS = 189

(a)
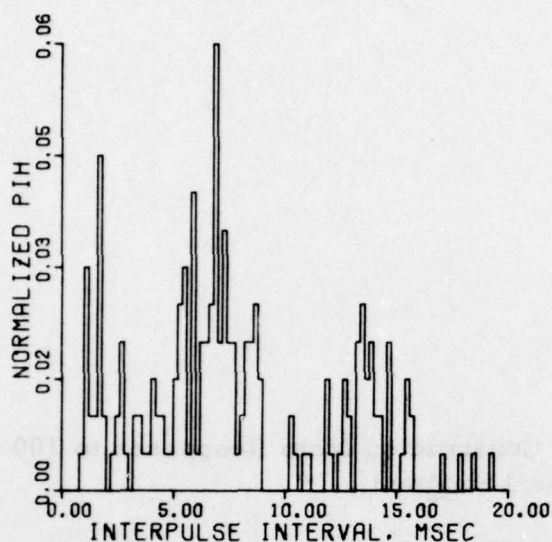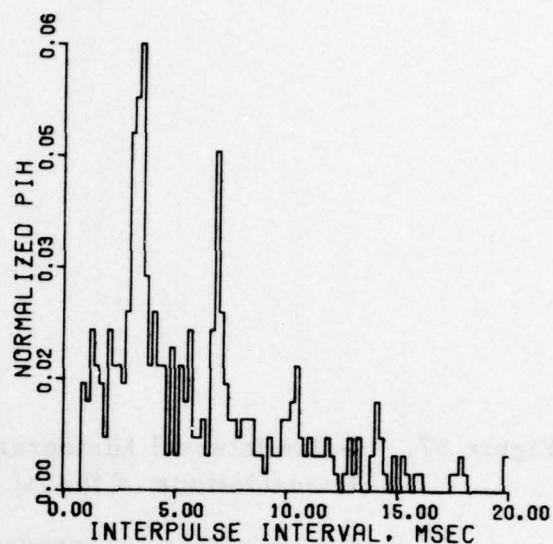
FIGURE   BASSETT.J . 03/31/76.3. 4.
DEFINING INTERVALS 460 TO 640
AVERAGE = 6.34   NUMBER OF INTERVALS = 386

(b)
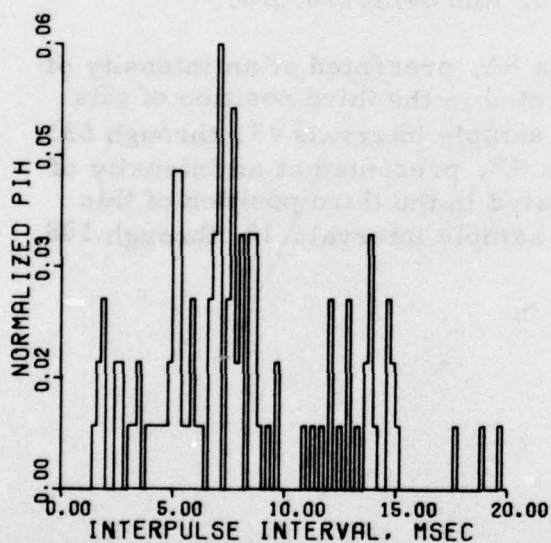
FIGURE   710627   . 11.. 14.
DEFINING INTERVALS 850 TO 999
AVERAGE = 6.76   NUMBER OF INTERVALS = 111

(c)
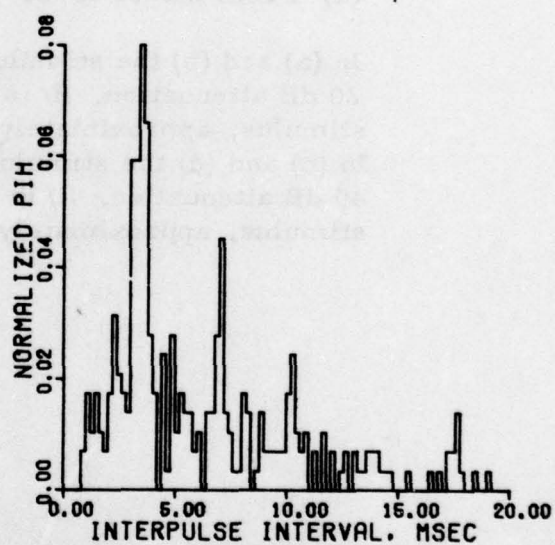
FIGURE   BASSETT.J . 04/12/76.3. 2.
DEFINING INTERVALS 850 TO 999
AVERAGE = 6.59   NUMBER OF INTERVALS = 299

(d)

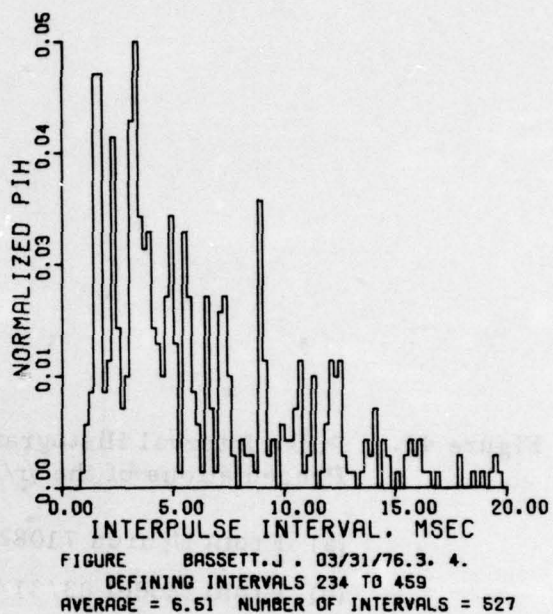Figure 57.   Pulse Interval Histograms Constructed from Responses to 100
Presentations of the /i/ Vowel Segment.

(a) From Neuron 710827/11, Run 16.

(b) From Model 03/31/76.3, Run 04/05/76.4/2.

(c) From Neuron 710827/11, Run 9.
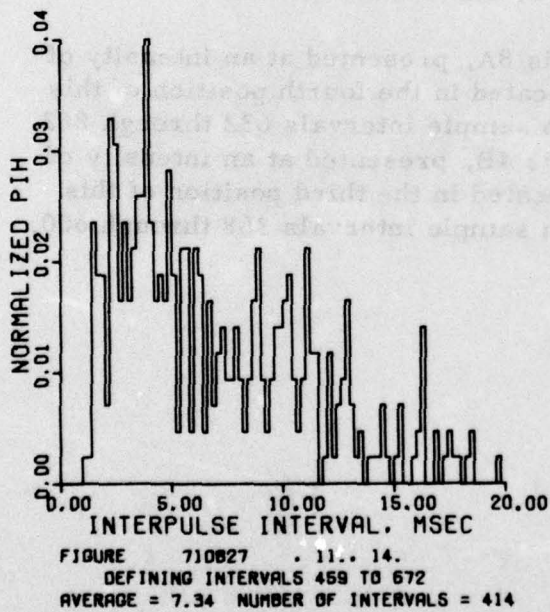
(d) From Model 03/31/76.3, Run 04/12/76.3/1.

In (a) and (b) the stimulus is 8A, presented at an intensity of
20 dB attenuation. /i/ is located in the third position of this
stimulus, approximately in sample intervals 451 through 631.
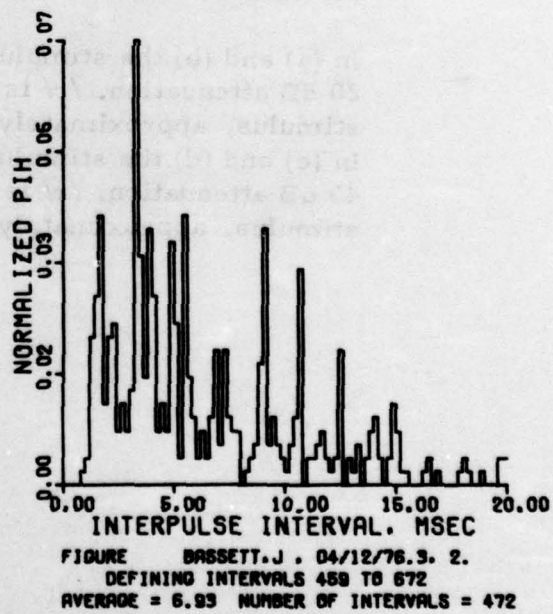In (c) and (d) the stimulus is 4B, presented at an intensity of
40 dB attenuation. /i/ is located in the third position of this
stimulus, approximately in sample intervals 12 through 188.
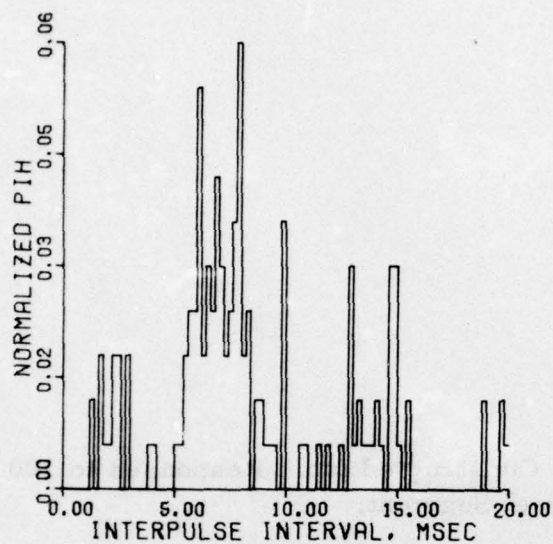
FIGURE   710627   . 11.. 16.
DEFINING INTERVALS 451 TO 631
AVERAGE = 10.28   NUMBER OF INTERVALS = 165

(a)
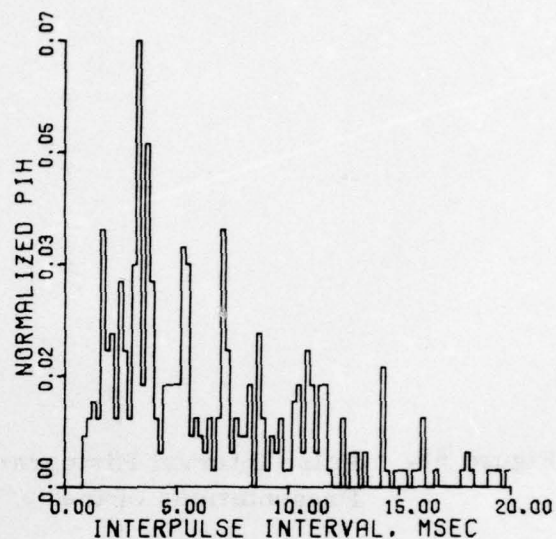
FIGURE   BASSETT.J . 04/05/76.4. 2.
DEFINING INTERVALS 451 TO 631
AVERAGE = 6.68   NUMBER OF INTERVALS = 380

(b)
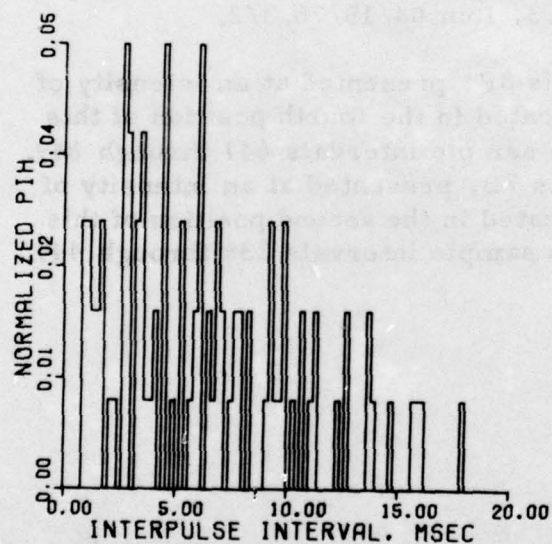
FIGURE   710627   . 11.. 9.
DEFINING INTERVALS 12 TO 168
AVERAGE = 8.22   NUMBER OF INTERVALS = 103

(c)
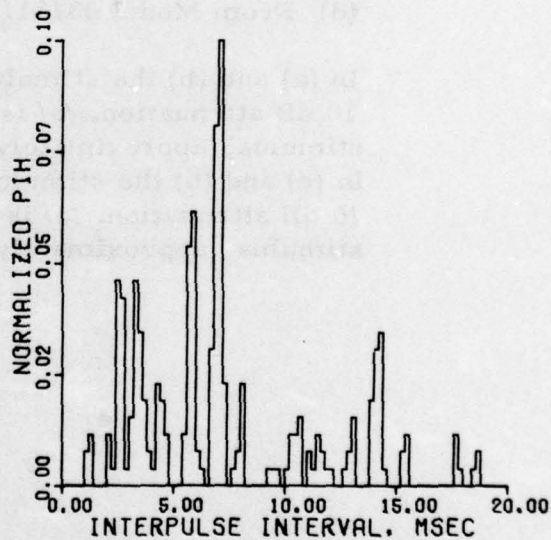
FIGURE   BASSETT.J . 04/12/76.3. 1.
DEFINING INTERVALS 12 TO 168
AVERAGE = 7.95   NUMBER OF INTERVALS = 262

(d)

131

Figure 58.   Pulse Interval Histograms Constructed from Responses to 100 Presentations of the /o/ Vowel Segment.

(a) From Neuron 710827/11, Run 7.

(b) From Model 03/31/76.3, Run 03/31/76.3/4.

(c) From Neuron 710827/11, Run 15.

(d) From Model 03/31/76.3, Run 04/15/76.3/2.

In (a) and (b) the stimulus is 3B, presented at an intensity of 10 dB attenuation. /o/ is located in the fourth position of this stimulus, approximately in sample intervals 641 through 849. In (c) and (d) the stimulus is 7B, presented at an intensity of 10 dB attenuation. /o/ is located in the second position of this stimulus, approximately in sample intervals 235 through 449.
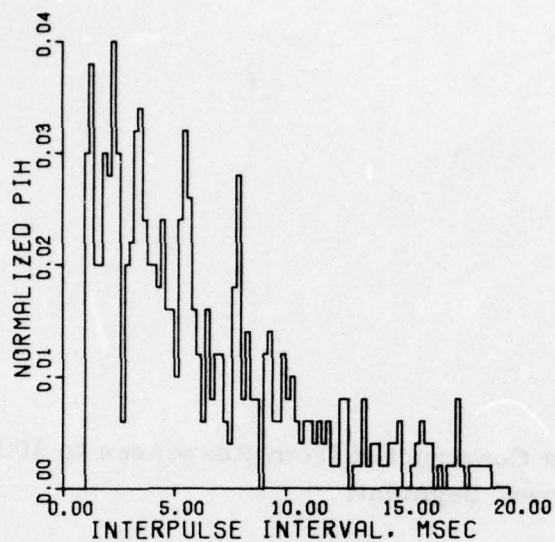
FIGURE   710827   . 11.. 7.
DEFINING INTERVALS 641 TO 849
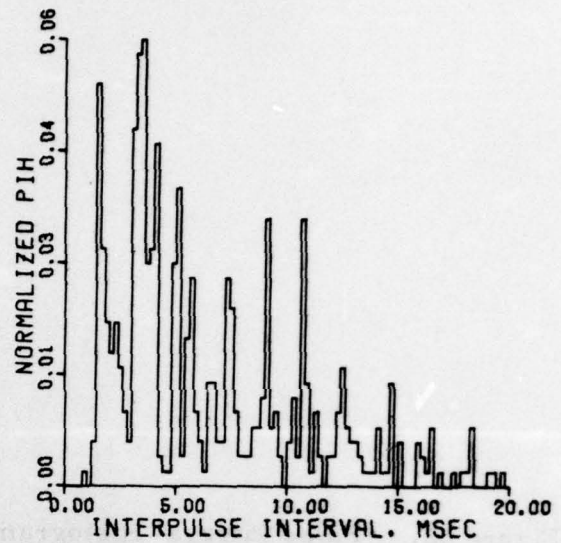AVERAGE = 6.51   NUMBER OF INTERVALS = 496
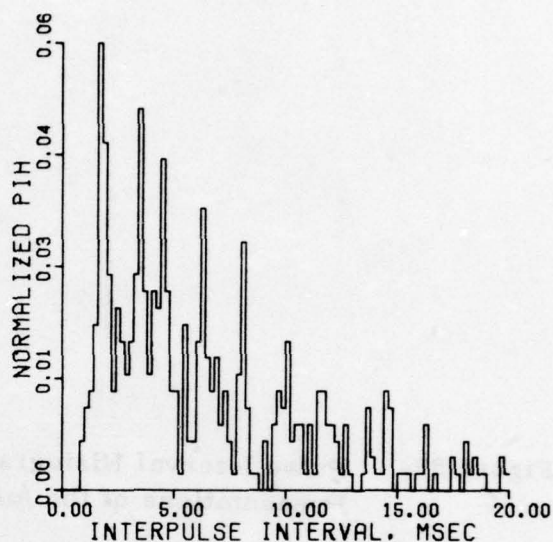
(a)

FIGURE   BASSETT.J . 03/31/76. 3. 4.
DEFINING INTERVALS 641 TO 849
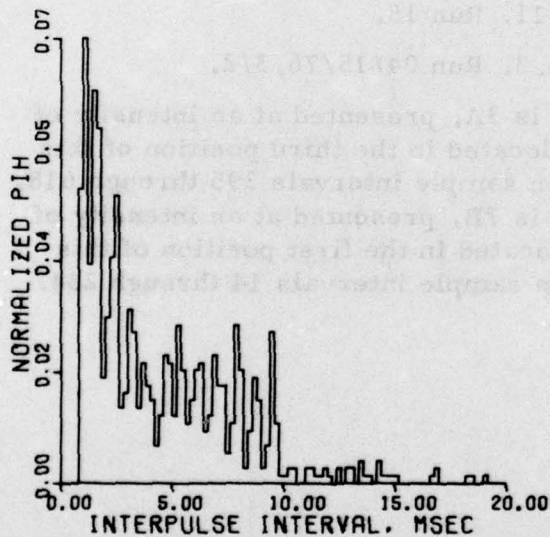AVERAGE = 6.56   NUMBER OF INTERVALS = 479

(b)
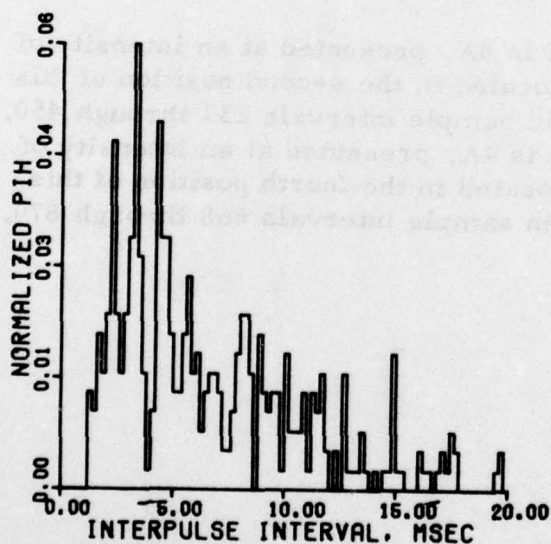
FIGURE   710827   . 11.. 15.
DEFINING INTERVALS 235 TO 449
AVERAGE = 7.22   NUMBER OF INTERVALS = 412
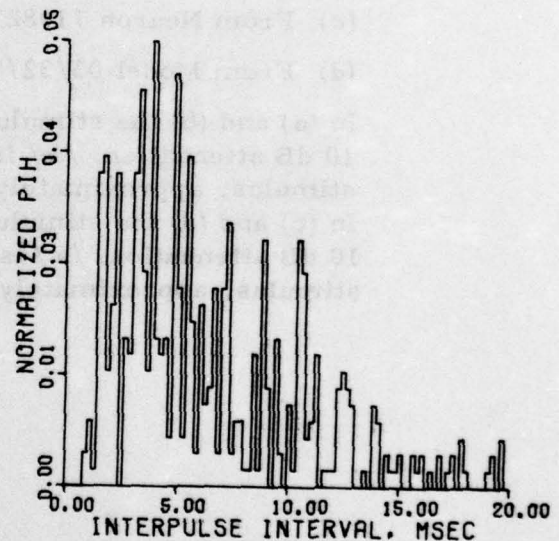
(c)
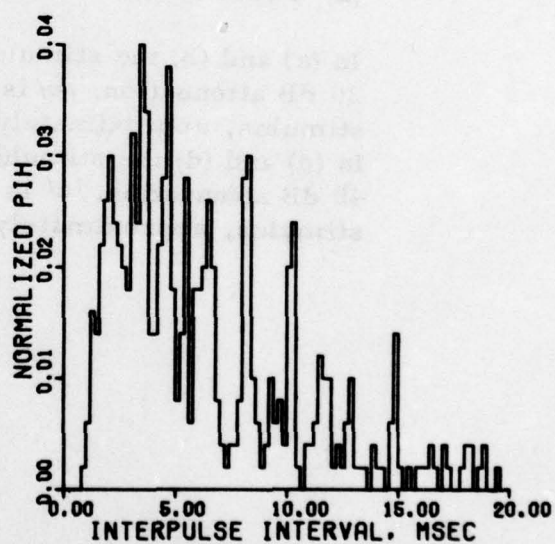
FIGURE   BASSETT.J . 04/15/76. 3. 2.
DEFINING INTERVALS 235 TO 449
AVERAGE = 6.66   NUMBER OF INTERVALS = 461

(d)

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Figure 59.　Pulse Interval Histograms Constructed from Responses to 100 Presentations of the /o/ Vowel Segment.

(a)　From Neuron 710827/11, Run 16.

(b)　From Model 03/31/76.3, Run 04/05/76.4/2.

(c)　From Neuron 710827/11, Run 8.

(d)　From Model 03/31/76.3, Run 04/15/76.3/1.

In (a) and (b) the stimulus is 8A, presented at an intensity of 20 dB attenuation. /o/ is located in the second position of this stimulus, approximately in sample intervals 233 through 450. In (c) and (d) the stimulus is 4A, presented at an intensity of 40 dB attenuation. /o/ is located in the fourth position of this stimulus, approximately in sample intervals 668 through 879.
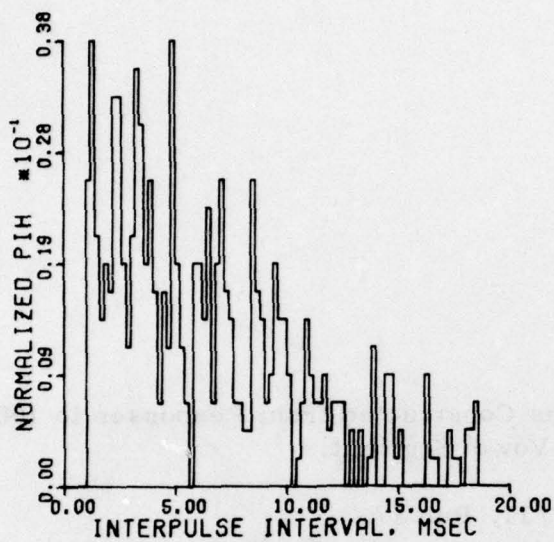
FIGURE   710827   . 11.. 16.
DEFINING INTERVALS 233 TO 450
AVERAGE = 7.65   NUMBER OF INTERVALS = 361

(a)

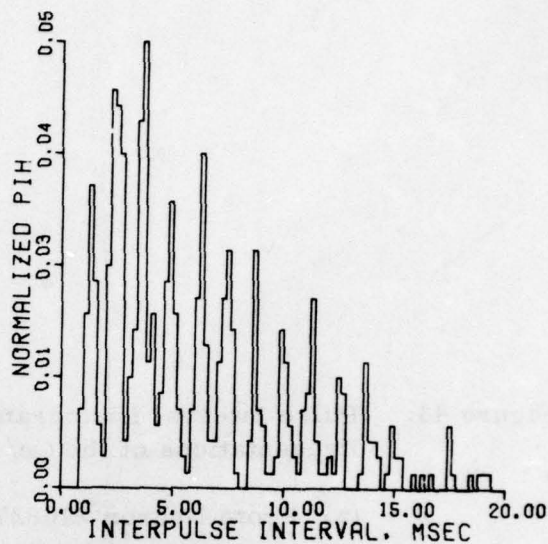FIGURE   BASSETT.J . 04/05/76.4. 2.
DEFINING INTERVALS 233 TO 450
AVERAGE = 7.01   NUMBER OF INTERVALS = 476

(b)

FIGURE   710827   . 11.. 6.
DEFINING INTERVALS 668 TO 679
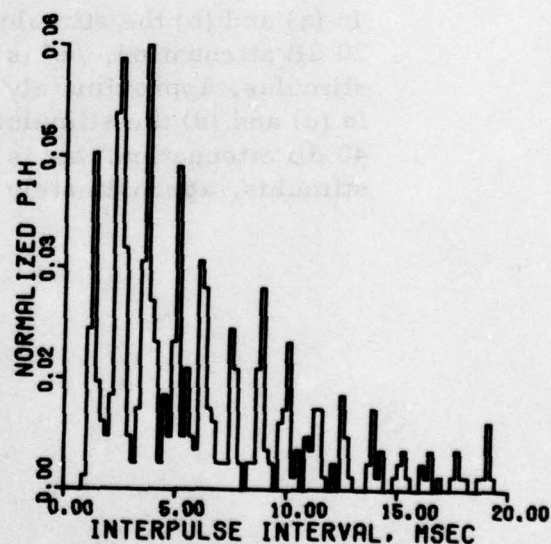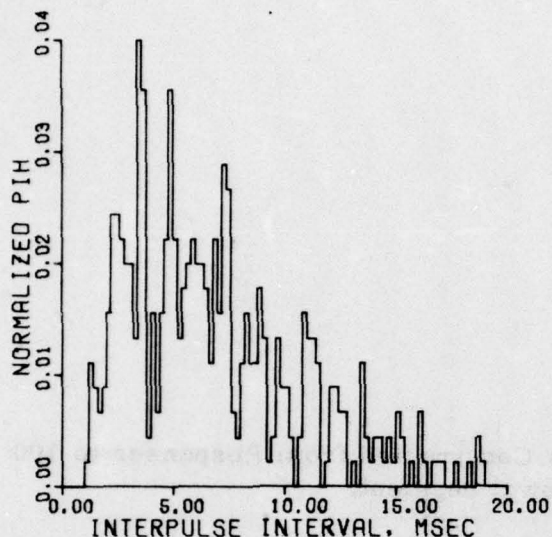AVERAGE = 11.21   NUMBER OF INTERVALS = 114

(c)

FIGURE   BASSETT.J . 04/15/76.3. 1.
DEFINING INTERVALS 668 TO 679
AVERAGE = 7.07   NUMBER OF INTERVALS = 480
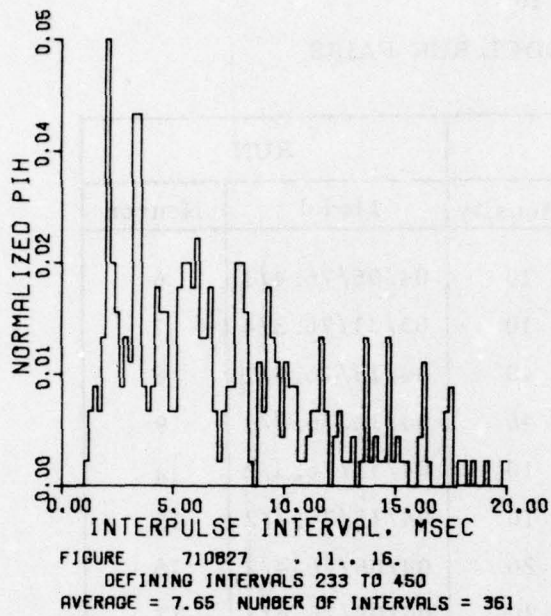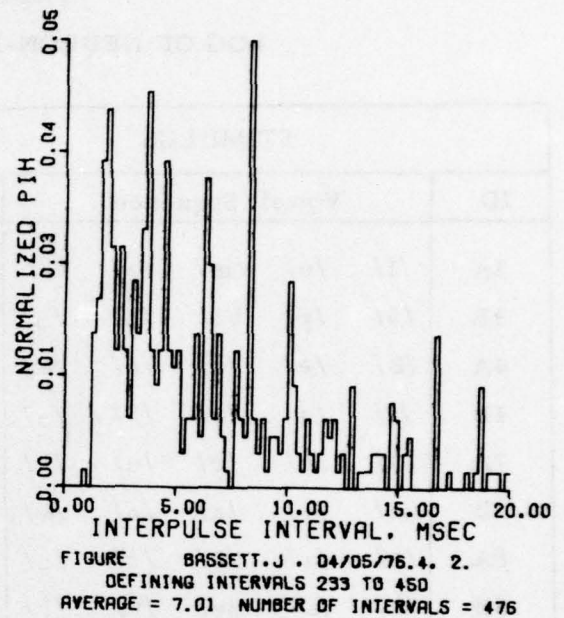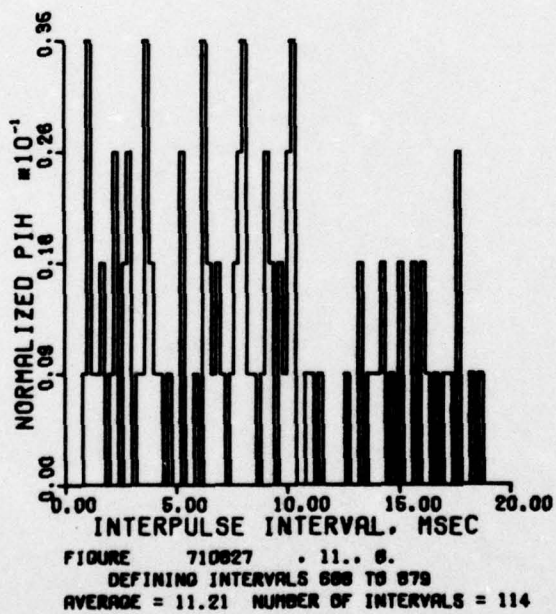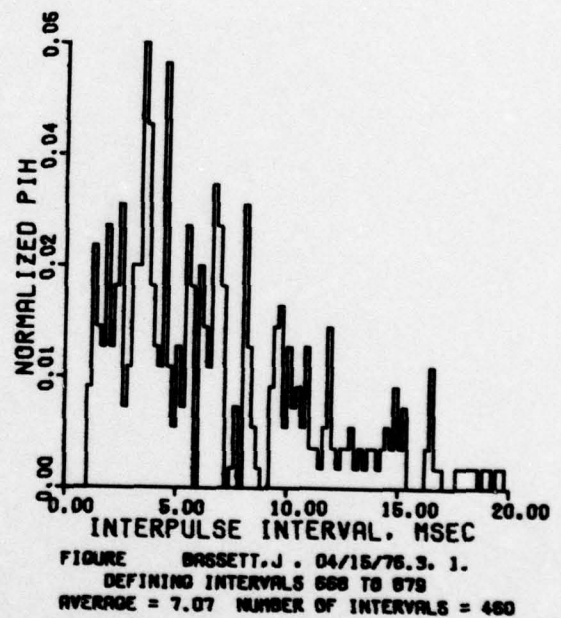
(d)

TABLE 10

LOG OF NEURON-MODEL RUN PAIRS

	STIMULUS						RUN	
ID	Vowel Sequence					Intensity	Model	Neuron
3A	/I/	/u/	/æ/	/a/	/ɛ/	10	04/05/76.4/1	6
3B	/ɔ/	/ɻ/	/i/	/o/	/ə/	10	03/31/76.3/4	7
4A	/ɛ/	/ə/	/a/	/o/	/æ/	40	04/15/76.3/1	8
4B	/i/	/u/	/ɻ/	/I/	/ɔ/	40	04/12/76.3/1	9
7A	/ɔ/	/I/	/ɻ/	/u/	/i/	10	04/12/76.3/2	14
7B	/æ/	/o/	/a/	/ə/	/ɛ/	10	04/15/76.3/2	15
8A	/ə/	/o/	/i/	/ɻ/	/ɔ/	20	04/05/76.4/2	16
8B	/ɛ/	/a/	/æ/	/u/	/I/	20	04/05/76.4/3	17

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TABLE 11
PEAK OCCURRENCE TABLE, VOWEL /ṛ/

Interpulse Interval	710827/11 Run 7	03/31/76.3 Run 4	710827/11 Run 14	04/12/76.3 Run 2	710827/11 Run 16	04/05/76.4 Run 2	710827/11 Run 9	04/12/76.3 Run 1
1.0						.002		
1.2							.158	.013
1.4								
1.6	.159	.110	.046			.087	.159	
1.8				.085	.049			.087
2.0								
2.2								
2.4	.118	.076	.072	.057	.092	.053		.057
2.6							.097	
2.8				.030				.032
3.0			.058					
3.2	.098						.068	
3.4		.129		.121	.061			.106
3.6						.140		
3.8							.048	
4.0		.078	.092	.087	.075			.081
4.2	.052					.078		
4.4								
4.6	.081		.053		.066			.038
4.8							.052	
5.0		.072	.065	.072	.061			.076
5.2						.070		
5.4							.056	
5.6	.059	.055	.048	.064	.061			.063
5.8						.055		
6.0								
6.2			.046					.034
6.4	.047			.017	.056		.047	
6.6		.034						
6.8			.029			.032		.038
7.0				.038			.045	
7.2								

No. Sample Intervals	226	226	214	214	231	231	233	233
Average	6.07	6.51	7.34	6.93	7.34	6.80	4.69	6.78
Number Intervals	572	527	414	472	412	527	805	528
Vowel Location	3B(2)	3B(2)	7A(3)	7A(3)	8A(4)	8A(4)	4B(3)	4B(3)
Intensity	10	10	10	10	20	20	40	40

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TABLE 12

PEAK OCCURRENCE TABLE, VOWEL /æ/

Interpulse Interval	710827/11 Run 6	04/05/76.4 Run 1	710827/11 Run 15	04/15/76.3 Run 2	710827/11 Run 17	04/05/76.4 Run 3	710827/11 Run 8	04/15/76.3 Run 1
1.0								
1.2							.123	.101
1.4	.085	.081	.109	.008	.024	.057		
1.6								
1.8								
2.0	.049						.036	
2.2								.034
2.4		.118						
2.6	.085			.153	.075	.151	.118	.115
2.8			.151					
3.0								
3.2							.021	
3.4	.087		.123					.063
3.6					.094			
3.8		.110		.125		.399	.169	.183
4.0	.061							
4.2		.043			.028			
4.4								
4.6	.035			.043				
4.8			.099					
5.0	.068	.079			.085	.090	.123	.120
5.2				.076				
5.4								
5.6			.033					
5.8							.041	
6.0					.066			
6.2	.052			.069			.046	
6.4		.079	.089			.098		
6.6	.045						.031	.067
6.8								
7.0								

No. Sample Intervals	224	224	221	221	221	221	120	120
Average	7.06	6.43	5.46	6.47	7.41	6.48	5.29	5.66
Number Intervals	425	534	677	510	195	208	424	509
Vowel Location	3A(3)	3A(3)	7B(1)	7B(1)	8B(3)	8B(3)	4A(5)	4A(5)
Intensity	10	10	10	10	20	20	40	40

TABLE 13

PEAK OCCURRENCE TABLE, VOWEL /ɔ/

Interpulse Interval	710827/11 Run 7	3/31/76.3 Run 4	710827/11 Run 14	4/12/76.3 Run 2	710827/11 Run 16	04/05/76.4 Run 2	710827/11 Run 9	4/12/76.3 Run 1
1.0								
1.2								
1.4	.270				.040			
1.6		.071	.155	.077		.112	.120	.047
1.8								
2.0		.094				.089		.171
2.2							.045	
2.4	.112		.100	.069				
2.6					.080		.023	
2.8								
3.0								.061
3.2		.075		.087		.070		
3.4								.108
3.6	.091		.117	.119		.143	.090	
3.8		.121						.123
4.0					.100			
4.2				.040		.031		
4.4								
4.6			.040					
4.8	.082							
5.0		.096	.082					
5.2					.095	.097	.060	.059
5.4				.102				.052
5.6		.060						
5.8					.065			.042
6.0						.027		
6.2	.046		.063		.060			
6.4								.027
6.6					.050		.023	.057
6.8		.048						
7.0							.023	

No. Sample Intervals	218	218	226	226	137	137	194	194
Average	4.38	6.63	5.23	6.60	7.11	6.28	9.10	7.26
Number Intervals	842	481	742	519	200	258	133	407
Vowel Location	3B(1)	3B(1)	7A(1)	7A(1)	8A(5)	8A(5)	4B(5)	4B(5)
Intensity	10	10	10	10	20	20	40	40

TABLE 14

PEAK OCCURRENCE TABLE, VOWEL /a/

Interpulse Interval	710827/11 Run 6	04/05/76.4 Run 1	710827/11 Run 15	04/15/76.3 Run 2	710827/11 Run 17	04/05/76.4 Run 3	710827/11 Run 8	04/15/76.3 Run 1
1.0								
1.2	.062					.048	.098	
1.4		.058		.078	.016			.059
1.6						.055		
1.8			.053					
2.0	.062						.065	
2.2		.058	.045	.072	.075			
2.4	.059							.098
2.6		.087		.082		.123		
2.8	.077		.064				.079	
3.0					.096			
3.2								
3.4								
3.6							.071	
3.8	.074	.121		.099	.087			.111
4.0			.095			.093	.084	
4.2								
4.4								
4.6					.078	.039		
4.8	.065	.087	.095	.068			.084	.093
5.0					.064			
5.2						.053		.063
5.4				.052				
5.6	.056	.020						
5.8			.062		.068		.044	
6.0	.067			.029				
6.2					.066			
6.4		.052		.035		.052		
6.6							.033	
6.8	.036		.033					
7.0		.019		.027	.064			

	710827/11 Run 6	04/05/76.4 Run 1	710827/11 Run 15	04/15/76.3 Run 2	710827/11 Run 17	04/05/76.4 Run 3	710827/11 Run 8	04/15/76.3 Run 1
No. Sample Intervals	222	222	218	218	241	241	218	218
Average	7.61	6.94	7.45	6.61	6.66	6.68	6.16	6.85
Number Intervals	338	481	419	485	561	562	478	460
Vowel Location	3A(4)	3A(4)	7B(3)	7B(3)	8B(2)	8B(2)	4A(3)	4A(3)
Intensity	10	10	10	10	20	20	40	40

TABLE 15

PEAK OCCURRENCE TABLE, VOWEL /I/

Interpulse Interval	710827/11 Run 6	04/05/76.4 Run 1	710827/11 Run 14	4/12/76/3 Run 3	710827/11 Run 17	04/05/76.4 Run 3	710827/11 Run 9	4/12/76/3 Run 1
1.0		.009		.010				
1.2	.079						.068	
1.4								
1.6				.042				
1.8								.090
2.0	.164		.080					
2.2		.102		.130	.034	.169	.040	
2.4			.080					
2.6					.059	.061	.011	
2.8	.066	.037						
3.0			.051					
3.2	.068							
3.4			.046				.034	
3.6								
3.8	.115		.068		.076			.172
4.0								
4.2	.092	.133	.094	.138		.140	.023	
4.4								
4.6					.034		.023	
4.8								
5.0	.047		.041					
5.2		.022			.067			
5.4			.046					
5.6							.034	
5.8	.066	.098			.034			.101
6.0			.068	.092				
6.2					.025	.076	.023	
6.4								.071
6.6				.021	.017	.054		
6.8	.015	.022						
7.0			.041	.019	.101			

	710827/11 Run 6	04/05/76.4 Run 1	710827/11 Run 14	4/12/76/3 Run 3	710827/11 Run 17	04/05/76.4 Run 3	710827/11 Run 9	4/12/76/3 Run 1
No. Sample Intervals	202	202	221	221	147	147	205	205
Average	5.06	6.64	7.59	6.90	7.52	6.32	10.39	7.07
Number Intervals	617	459	413	478	119	278	177	424
Vowel Location	3A(1)	3A(1)	7A(2)	7A(2)	8B(5)	8B(5)	4B(4)	4B(4)
Intensity	10	10	10	10	20	20	40	40

TABLE 16
PEAK OCCURRENCE TABLE, VOWEL /ɛ/

Interpulse Interval	710827/11 Run 6	04/05/76.4 Run 1	710827/11 Run 15	04/15/76.3 Run 2	710827/11 Run 17	04/05/76.4 Run 3	710827/11 Run 8	04/15/76.3 Run 1
1.0								
1.2								
1.4	.122		.043				.054	
1.6		.122			.057			.064
1.8				.183		.151		
2.0			.069		.059			.059
2.2							.060	
2.4								
2.6		.009						
2.8	.052		.096	.011	.057			.023
3.0							.042	
3.2		.116				.118		.138
3.4	.058			.204	.077			
3.6		.131				.130		.151
3.8			.086		.074			
4.0		.021		.043				
4.2								
4.4	.047							.034
4.6				.075			.054	
4.8		.086			.072			
5.0						.104		
5.2	.064	.104	.103	.108				.093
5.4					.062		.030	
5.6								
5.8	.064		.052	.016			.048	
6.0					.047			
6.2			.052					
6.4		.045						
6.6				.043		.069		
6.8		.060	.043		.089			.108
7.0				.059		.066	.054	

	710827/11 Run 6	04/05/76.4 Run 1	710827/11 Run 15	04/15/76.3 Run 2	710827/11 Run 17	04/05/76.4 Run 3	710827/11 Run 8	04/15/76.3 Run 1
No. Sample Intervals	159	159	105	105	199	199	211	211
Average	7.26	6.23	6.81	5.26	6.70	6.64	9.62	6.55
Number Intervals	172	336	116	186	405	423	167	471
Vowel Location	3A(5)	3A(5)	7B(5)	7B(5)	3A(5)	3A(5)	4A(1)	4A(1)
Intensity	10	10	10	10	20	20	40	40

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TABLE 17
PEAK OCCURRENCE TABLE, VOWEL /u/

Interpulse Interval	710827/11 Run 6	04/05/76.4 Run 1	710827/11 Run 14	4/12/76 Run 3	710827/11 Run 17	04/05/76.4 Run 3	710827/11 Run 9	4/12/76.3 Run 3
1.0		.003		.003		.003		
1.2							.083	
1.4	.052							
1.6								
1.8			.064				.083	
2.0	.079							.109
2.2				.127	.061	.125	.083	
2.4	.079	.196	.036					.182
2.6				.161		.128		
2.8	.070						.060	
3.0					.056			
3.2				.025		.045	.048	
3.4								
3.6	.061		.060		.041	.003		
3.8							.065	
4.0								
4.2	.076				.066			
4.4								
4.6		.126		.144				
4.8			.108		.066	.148		.187
5.0		.090		.132			.024	
5.2	.052							.083
5.4			.056				.018	
5.6		.014		.011				.003
5.8					.041	.011	.030	
6.0	.044	.006		.008				
6.2			.064		.046		.054	
6.4	.035							
6.6								
6.8	.050					.061	.042	
7.0			.044		.081			
7.2				.090				.138

	710827/11 Run 6	04/05/76.4 Run 1	710827/11 Run 14	4/12/76 Run 3	710827/11 Run 17	04/05/76.4 Run 3	710827/11 Run 9	4/12/76.3 Run 3
No. Sample Intervals	179	179	177	177	179	179	179	179
Average	6.61	6.91	7.84	6.53	8.75	6.85	8.37	6.78
Number Intervals	343	357	250	355	197	359	168	385
Vowel Location	3A(2)	3A(2)	7A(4)	7A(4)	8B(4)	8B(4)	4B(2)	4B(2)
Intensity	10	10	10	10	20	20	40	40

TABLE 18

PEAK OCCURRENCE TABLE, VOWEL /ə/

Interpulse Interval	710827/11 Run 7	3/32/76.3 Run 4	710827/11 Run 15	04/15/76.3 Run 2	710827/11 Run 16	04/05/76.4 Run 2	710827/11 Run 8	04/15/76.3 Run 1
1.0		.019		.032		.010		
1.2	.074				.017		.134	
1.4			.017					
1.6		.063		.086		.075		
1.8	.095				.055		.134	
2.0		.082	.027	.088		.097		.078
2.2								
2.4								
2.6	.107		.086					
2.8		.135		.070	.105		.065	.086
3.0						.097		
3.2		.123						.070
3.4				.078		.089	.051	
3.6	.070		.081		.115			.053
3.8								
4.0								.064
4.2		.076	.081			.050		
4.4				.084	.076		.058	.101
4.6	.045							
4.8						.075		
5.0	.033							
5.2		.044	.073		.072			.053
5.4				.051		.044	.049	
5.6								.043
5.8		.051		.045			.058	
6.0	.074		.066			.067		
6.2					.088			.041
6.4	.062		.064					
6.6		.035						
6.8					.057			
7.0						.022	.055	.056

	710827/11 Run 7	3/32/76.3 Run 4	710827/11 Run 15	04/15/76.3 Run 2	710827/11 Run 16	04/05/76.4 Run 2	710827/11 Run 8	04/15/76.3 Run 1
No. Sample Intervals	150	150	235	235	221	221	223	223
Average	6.49	6.11	7.62	6.76	6.18	6.71	5.83	6.85
Number Intervals	243	316	409	412	581	496	567	486
Vowel Location	3B(5)	3B(5)	7B(4)	7B(4)	8A(1)	8A(1)	4A(2)	4A(2)
Intensity	10	10	10	10	20	20	40	40

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TABLE 19

PEAK OCCURRENCE TABLE, VOWEL /i/

Interpulse Interval	710827/11 Run 7	3/31/76.3 Run 4	710827/11 Run 14	4/12/76/3 Run 2	710827/11 Run 16	04/05/76.4 Run 2	710827/11 Run 9	4/12/76/3 Run 1
1.0								
1.2	.048	.028		.033			.078	
1.4					.012	.034		.019
1.6		.054		.037				
1.8	.069				.024	.071	.049	
2.0			.018					
2.2		.049				.055		
2.4				.067	.042		.020	
2.6			.018			.063		.092
2.8	.037						.087	
3.0					.018			
3.2								
3.4						.118		.095
3.6	.026	.153	.009	.197			.078	
3.8						.100		
4.0					.012			
4.2	.032	.062					.029	
4.4								.046
4.6				.027			.049	
4.8								
5.0		.031		.040			.010	
5.2								
5.4		.036	.054	.040		.087	.029	
5.6	.064							
5.8		.044						
6.0	.053		.018			.026		.122
6.2				.017	.097		.068	
6.4	.023							
6.6					.073	.018	.029	
6.8								
7.0	.111	.098			.097		.058	

No. Sample Intervals	181	181	150	150	181	181	177	177
Average	8.46	6.34	8.78	6.59	10.28	6.68	8.22	7.96
Number Intervals	189	386	111	299	165	380	103	262
Vowel Location	3B(3)	3B(3)	7A(5)	7A(5)	8A(3)	8A(3)	4B(1)	4B(1)
Intensity	10	10	10	10	20	20	40	40

TABLE 20
PEAK OCCURRENCE TABLE, VOWEL /o/

Interpulse Interval	710827/11 Run 7	3/31/76.3 Run 4	710827/11 Run 15	04/15/76.3 Run 2	710827/11 Run 16	04/05/76.4 Run 2	710827/11 Run 8	04/15/76.3 Run 1
1.0						.002		
1.2							.053	
1.4	.089		.022	.037				.054
1.6					.028			
1.8		.121	.044				.026	
2.0	.079					.116		.059
2.2				.083	.091			
2.4	.099		.087				.035	
2.6		.054				.063		.061
2.8								
3.0					.042		.044	
3.2				.077		.053		
3.4			.117					
3.6	.091	.100		.102	.097			.111
3.8						.097	.061	
4.0					.053			
4.2		.063						
4.4			.087					
4.6	.058	.090				.074		.072
4.8				.087			.009	
5.0								
5.2						.036		.030
5.4							.026	
5.6	.083	.029		.050				.059
5.8			.061		.072			
6.0						.034	.009	
6.2			.039		.066			.041
6.4		.071				.071	.053	
6.6	.030			.069				
6.8			.041		.047			.074
7.0								
7.2								

No. Sample Intervals	209	209	215	215	218	218	212	212
Average	6.51	6.56	7.22	6.66	7.65	7.01	11.21	7.07
Number Intervals	496	479	412	481	361	476	114	460
Vowel Location	3B(4)	3B(4)	7B(2)	7B(2)	8A(2)	8A(2)	4A(4)	4A(4)
Intensity	10	10	10	10	20	20	40	40

8.4 STIMULUS ZERO-CROSSING INTERVAL HISTOGRAMS

Early in the modeling effort it became clear that the model usually produces pulses corresponding in time to the point where the stimulus crosses the time axis going positive. This suggests that peaks in the Model's PIHs, and hopefully the Neuron's too, should occur at the permutations of the intervals between these stimulus zero-crossing points. This observation has lead to the development of the Stimulus Zero-Crossing Interval Histogram or SIH. The sequence of intervals between zero-crossing points was generated for each vowel within a digitized stimulus. For example, (1.4, 1.2, 1.2, 1.4, 0.8, ...). A histogram is constructed by tallying the intervals taken one at a time, summed two at a time, in the manner (1.4 + 1.2), (1.2 + 1.2), (1.2 + 1.4), (1.4 + 0.8), ..., summed three at a time, in the manner (1.4 + 1.2 + 1.2), (1.2 + 1.2 + 1.4), (1.2 + 1.4 + 0.8), ..., and so on. These histograms are presented in Tables 21 through 30 for each of the four presentations of the ten vowels. Note the differences in the SIHs of the four presentations of a given vowel. This demonstrates the inherent digitization error in the stimulus generation procedure, since the four presentations are supposed to have exactly the same analog waveform.

8.5 A COMPARISON OF SIHs AND CORRESPONDING VOWEL PIHs

In this section tables are presented that provide the basis for a quantitative verification of the empirical observation that "the Model usually produces pulses corresponding in time to the point were the stimulus crosses the time axis going positive." If this statement is true, then it follows that peaks in the SIH should coincide with peaks in the corresponding vowel PIH.

Tables 31 through 50 were constructed to test this hypothesis. In each of these tables are four major columns, one for each presentation of a vowel. Each major column has two subcolumns. The left-hand subcolumn is labeled "SIH", and contains an "X" in the rows corresponding to the intervals where peaks occurred in the SIH. The right-hand subcolumn is labeled "PIH", and contains a number in the rows corresponding to the intervals where peaks occurred in the vowel PIH, as entered in the Peak Occurrence Tables. The number is the rank of the peak, where the rank is according to the size of the peaks in the Peak Occurrence Tables. A rank of 1 corresponds to the largest peak. This ranking, along with the column labeled "Number of PIH Peaks in this Interval," will be used in a later analysis.

An SIH peak and a peak in a corresponding vowel PIH are said to match if they fall within one sample interval of each other. The total number of peaks that don't match between an SIH and a comparable vowel PIH divided by the total number of peaks in the two histograms is the fraction of misplaced peaks for that pair. This computation is averaged over the four SIH-vowel PIH pairs associated with each vowel to give the average fraction of misplaced peaks. Each of these values is plotted in Figure 60 by vowel and according to whether the vowel PIH was from the Model or the Neuron. The vowels are arranged on a scale that measures the distance from the Neuron's characteristic frequency to the vowel formant closest to it.

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TABLE 21

STIMULUS ZERO-CROSSING INTERVALS TABLE VOWEL /ɪ/

INTERVAL	STIMULUS			
	3B	7A	8A	4B
.2	0	0	0	0
.4	0	0	0	0
.6	0	0	0	0
.8	3	3	3	2
1.0	1	1	1	0
1.2	0	1	0	0
1.4	5	2	2	3
1.6	11	12	13	10
1.8	9	9	10	9
2.0	0	0	0	0
2.2	1	0	0	0
2.4	7	8	8	6
2.6	0	0	0	0
2.8	0	1	0	0
3.0	1	0	0	2
3.2	9	5	5	4
3.4	6	11	12	8
3.6	4	2	3	3
3.8	2	1	1	2
4.0	9	6	5	5
4.2	1	5	6	3
4.4	0	0	0	0
4.6	0	1	0	0
4.8	1	1	1	3
5.0	10	7	7	5
5.2	4	5	2	4
5.4	2	0	0	1
5.6	6	5	4	6
5.8	7	9	10	5
6.0	1	2	2	2
6.2	0	1	0	0
6.4	0	0	0	0
6.6	7	2	2	5
6.8	3	6	8	2
7.0	0	0	0	0

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TABLE 22

STIMULUS ZERO-CROSSING INTERVALS TABLE VOWEL /æ/

INTERVAL	STIMULUS			
	3A	7B	8B	4A
.2	0	0	0	0
.4	1	0	0	0
.6	1	0	0	0
.8	1	0	1	0
1.0	0	0	0	0
1.2	25	21	22	13
1.4	9	13	11	4
1.6	1	0	0	1
1.8	1	0	0	0
2.0	0	0	1	0
2.2	1	0	0	0
2.4	16	12	12	8
2.6	16	17	18	7
2.8	2	4	2	2
3.0	1	0	0	0
3.2	0	0	1	0
3.4	1	0	0	0
3.6	9	6	4	4
3.8	19	16	21	8
4.0	4	9	6	4
4.2	2	1	0	0
4.4	0	0	1	0
4.6	0	0	0	0
4.8	5	3	2	2
5.0	18	11	12	7
5.2	9	13	16	5
5.4	2	4	0	1
5.6	0	0	1	0
5.8	0	0	0	0
6.0	3	0	0	1
6.2	10	8	6	4
6.4	12	14	20	7
6.6	1	7	3	2
6.8	0	1	0	0
7.0	0	0	0	0

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TABLE 23

STIMULUS ZERO-CROSSING INTERVALS TABLE VOWEL /ɔ/

		STIMULUS		
INTERVAL	3B	7A	8A	4B
.2	0	0	0	0
.4	0	0	0	0
.6	2	1	1	0
.8	2	3	2	0
1.0	0	0	0	0
1.2	0	0	0	0
1.4	5	4	3	8
1.6	14	16	9	7
1.8	0	0	0	1
2.0	5	5	3	4
2.2	6	3	3	0
2.4	2	5	2	3
2.6	0	0	0	1
2.8	0	0	0	2
3.0	5	4	3	3
3.2	4	6	3	0
3.4	3	3	1	5
3.6	9	7	5	5
3.8	8	7	6	3
4.0	2	5	1	5
4.2	0	0	0	0
4.4	0	0	0	0
4.6	0	0	0	0
4.8	0	0	0	3
5.0	8	7	4	6
5.2	8	8	5	1
5.4	6	6	4	8
5.6	2	2	0	0
5.8	4	5	4	1
6.0	2	3	1	3
6.2	0	0	0	0
6.4	0	0	0	4
6.6	8	7	4	1
6.8	3	3	2	1
7.0	2	4	2	3

TABLE 24

STIMULUS ZERO-CROSSING INTERVALS TABLE VOWEL /a/

		STIMULUS		
INTERVAL	3A	7B	8B	4A
.2	0	0	0	0
.4	0	0	0	0
.6	0	0	0	0
.8	0	0	2	0
1.0	9	8	7	9
1.2	13	14	15	9
1.4	9	8	12	5
1.6	3	4	3	2
1.8	0	0	0	0
2.0	1	2	1	3
2.2	9	8	11	6
2.4	4	6	4	1
2.6	14	8	14	7
2.8	5	7	6	7
3.0	0	2	2	0
3.2	4	3	1	4
3.4	2	5	7	1
3.6	8	5	7	4
3.8	9	7	7	7
4.0	7	9	11	7
4.2	3	3	3	0
4.4	0	1	1	0
4.6	3	4	2	2
4.8	8	8	11	7
5.0	10	6	5	9
5.2	5	7	11	0
5.4	4	3	4	3
5.6	0	2	2	1
5.8	3	4	0	1
6.0	6	3	6	10
6.2	10	11	14	2
6.4	7	6	5	3
6.6	3	4	5	4
6.8	1	2	1	1
7.0	0	0	0	0

TABLE 25

STIMULUS ZERO-CROSSING INTERVALS TABLE VOWEL /I/

		STIMULUS		
INTERVAL	3A	7A	8B	4B
.2	0	0	0	0
.4	0	0	0	0
.6	1	1	2	0
.8	3	4	2	0
1.0	1	0	0	0
1.2	0	0	1	0
1.4	3	3	2	0
1.6	3	1	2	0
1.8	4	4	4	3
2.0	8	7	7	13
2.2	6	9	9	4
2.4	2	0	2	0
2.6	2	5	2	0
2.8	1	0	0	0
3.0	0	0	0	0
3.2	0	0	1	0
3.4	3	1	1	0
3.6	2	3	3	0
3.8	5	3	0	1
4.0	7	6	10	14
4.2	6	7	8	4
4.4	0	3	1	0
4.6	4	4	2	0
4.8	1	1	2	0
5.0	0	0	0	0
5.2	0	0	0	0
5.4	1	0	1	0
5.6	4	4	2	0
5.8	5	1	2	1
6.0	7	7	8	12
6.2	3	6	6	5
6.4	2	4	4	0
6.6	4	1	2	0
6.8	1	4	2	0
7.0	0	0	0	0

TABLE 26

STIMULUS ZERO-CROSSING INTERVALS TABLE VOWEL /ɛ/

			STIMULUS	
INTERVAL	3A	73	8B	4A
.2	0	0	0	0
.4	0	0	0	0
.6	0	0	0	0
.8	0	0	0	0
1.0	0	0	0	0
1.2	0	0	0	0
1.4	0	0	0	1
1.6	13	7	14	14
1.8	3	2	4	6
2.0	2	2	4	2
2.2	0	0	0	1
2.4	0	0	0	0
2.6	0	0	0	0
2.8	0	0	0	0
3.0	0	0	0	0
3.2	6	2	8	9
3.4	5	4	5	7
3.6	3	4	6	6
3.8	1	0	2	1
4.0	0	0	0	0
4.2	0	0	0	0
4.4	0	0	0	0
4.6	0	0	0	0
4.8	4	0	4	4
5.0	5	4	4	7
5.2	5	4	7	9
5.4	2	1	5	2
5.6	0	0	0	0
5.8	0	0	0	0
6.0	0	0	0	0
6.2	0	0	0	0
6.4	0	0	1	1
6.6	5	2	3	4
6.8	7	2	7	12
7.0	3	4	8	4

TABLE 27

STIMULUS ZERO-CROSSING INTERVALS TABLE VOWEL /u/

		STIMULUS		
INTERVAL	3A	7A	8B	4B
.2	0	0	0	0
.4	3	4	2	0
.6	1	0	1	0
.8	0	0	0	0
1.0	0	0	0	0
1.2	0	0	0	0
1.4	0	0	0	0
1.6	0	0	0	0
1.8	1	1	0	0
2.0	4	2	1	0
2.2	5	7	8	2
2.4	5	5	3	3
2.6	8	8	7	0
2.8	0	0	2	0
3.0	0	0	0	0
3.2	0	0	0	0
3.4	0	0	0	0
3.6	0	0	0	0
3.8	0	0	0	0
4.0	0	0	0	0
4.2	1	1	0	1
4.4	2	1	0	0
4.6	9	8	6	0
4.8	2	4	6	3
5.0	7	7	4	1
5.2	1	1	4	0
5.4	0	0	0	0
5.6	0	0	0	0
5.8	0	0	0	0
6.0	0	0	0	0
6.2	0	0	0	0
6.4	1	1	0	0
6.6	3	1	0	1
6.8	2	4	2	0
7.0	5	2	2	1

TABLE 28
STIMULUS ZERO-CROSSING INTERVALS TABLE VOWEL /ə/

INTERVAL	STIMULUS 3B	7B	8A	4A
.2	0	0	0	0
.4	0	0	0	0
.6	3	2	1	0
.8	0	2	1	0
1.0	3	6	4	0
1.2	5	7	6	1
1.4	2	4	3	4
1.6	10	12	9	10
1.8	4	5	5	0
2.0	1	5	4	3
2.2	3	4	4	5
2.4	0	0	0	1
2.6	1	3	3	0
2.8	7	5	3	1
3.0	5	12	7	4
3.2	4	5	6	5
3.4	1	3	3	0
3.6	4	5	4	8
3.8	2	4	4	1
4.0	2	1	0	1
4.2	3	7	6	2
4.4	4	5	5	3
4.6	5	7	3	4
4.8	3	6	6	0
5.0	0	1	1	0
5.2	3	5	3	8
5.4	2	4	5	1
5.6	3	3	2	3
5.8	4	5	5	3
6.0	6	11	8	2
6.2	3	5	2	0
6.4	0	2	4	0
6.6	1	0	0	3
6.8	1	4	2	6
7.0	3	5	4	0

TABLE 29

STIMULUS ZERO-CROSSING INTERVALS TABLE VOWEL /i/

INTERVAL	STIMULUS			
	3B	7A	8A	4B
.2	0	0	0	0
.4	0	0	0	0
.6	0	0	0	0
.8	0	0	0	0
1.0	1	0	0	0
1.2	0	2	0	0
1.4	4	2	4	0
1.6	0	0	0	0
1.8	0	0	0	0
2.0	0	0	0	0
2.2	2	0	0	0
2.4	3	2	4	0
2.6	0	1	0	0
2.8	0	0	0	0
3.0	0	1	0	0
3.2	3	2	0	1
3.4	3	1	5	4
3.6	1	0	0	1
3.8	3	3	4	3
4.0	0	0	0	0
4.2	0	0	0	0
4.4	0	2	0	0
4.6	2	2	0	0
4.8	2	0	4	0
5.0	0	0	0	0
5.2	0	0	0	0
5.4	1	0	0	0
5.6	2	1	0	0
5.8	2	2	4	0
6.0	0	0	0	0
6.2	0	0	0	0
6.4	1	0	0	0
6.6	0	0	0	0
6.8	2	2	0	0
7.0	5	5	0	3

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TABLE 30

STIMULUS ZERO-CROSSING INTERVALS TABLE VOWEL /o/

INTERVAL	STIMULUS			
	3B	73	8A	4A
.2	0	0	0	0
.4	0	0	0	0
.6	0	0	0	0
.8	0	0	0	0
1.0	0	1	1	0
1.2	4	3	4	0
1.4	3	2	0	2
1.6	1	4	5	4
1.8	11	9	10	19
2.0	4	6	5	19
2.2	0	0	0	0
2.4	0	0	1	1
2.6	3	2	1	3
2.8	1	3	4	3
3.0	4	3	4	0
3.2	0	1	0	0
3.4	4	2	0	4
3.6	6	6	10	7
3.8	4	6	5	0
4.0	0	1	0	0
4.2	0	0	0	0
4.4	3	2	0	0
4.6	5	5	0	3
4.8	4	5	8	5
5.0	0	0	0	1
5.2	4	1	0	0
5.4	1	5	5	2
5.6	4	4	5	3
5.8	0	1	0	0
6.0	0	0	0	0
6.2	3	1	0	5
6.4	9	17	5	3
6.6	0	7	8	2
6.8	4	3	4	2
7.0	4	0	0	1

TABLE 31

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR
THE FOUR PRESENTATIONS OF THE VOWEL /r/ TO MODEL 03/31/76.3

Interval	Number of PIH Peaks In This Interval	03/31/76.3/4		04/12/76.3/2		04/05/76.4/2		04/12/76.3/1	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.2	1								11
1.6	2	X	2	X		X	2	X	2
1.8	2				3				
2.4	4	X	4	X	6	X	6	X	6
2.8	2	X		X	8				10
3.2	0	X							
3.4	3		1	X	1	X		X	1
3.6	1						1		
4.0	3	X	3	X	2			X	3
4.2	1					X	3		
4.6	0								7
5.0	3	X	5	X	4	X		X	4
5.2	1					X	4		
5.6	3		6		5			X	5
5.8	1	X		X		X	5		
6.2	1								9
6.4	1				9				
6.6	1	X	7					X	
6.8	2			X		X	7		7
7.0	1				7				

TABLE 32

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR
THE FOUR PRESENTATIONS OF THE VOWEL /æ/ TO MODEL 03/31/76.3

Interval	Number of PIH Peaks In This Interval	04/05/76.4/1		04/15/76.3/2		04/05/76.4/3		04/15/76.3/1	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.2	1	X		X		X		X	4
1.4	3		3		3		5		
2.0	0					X			
2.2	1								7
2.4	1	X	1					X	
2.6	3	X		X	1	X	1		3
3.2	0					X			
3.4	1								6
3.8	4	X	2	X	2	X	2	X	1
4.2	1		6						
4.4	0					X			
4.6	1				6				
5.0	3	X	4				4	X	2
5.2	1			X	4	X			
5.6	1				7	X			
6.2	1				5				
6.4	3	X	4	X		X	3	X	5

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TABLE 33

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /ɔ/ TO MODEL 03/31/76.3

Interval	Number of PIH Peaks In This Interval	3/31/76.3/4		4/12/76.3/2		4/05/76.4		4/12/76.3/1	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.4	1							X	7
1.6	3	X	5	X	4	X	2	X	
2.0	3	X	3	X		X	4	X	3
2.2		X				X			
2.4	1			X	5			X	
3.0	1	X				X		X	4
3.2	3		4	X	3	X	5		
3.4	1							X	2
3.6	2	X		X	1		1	X	
3.8	2		1	X		X			1
4.0								X	
4.2	2				6		6	X	
5.0	2	X	2					X	5
5.2	1	X		X		X	3		
5.4	2				2			X	6
5.6	1		6						
5.8	1	X		X		X			8
6.0	1						7	X	
6.4	1							X	9
6.6	1	X		X		X			
6.8	1		7						

TABLE 34

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /a/ TO MODEL 03/31/76.3

Interval	Number of PIH Peaks In This Interval	04/05/76.4/1		04/15/76.3/2		04/05/76.4/3		04/15/76.3/1	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.2	1	X		X		X	6	X	
1.4	3		5		3				6
1.6	1						3		
2.2	2	X	5	X	4	X		X	
2.4	1								2
2.6	3	X	2	X	2	X	1	X	
2.8	0							X	
3.2	0	X						X	
3.8	3	X	1		1			X	1
4.0	1			X		X	2	X	
4.6	1						7		
4.8	3		2	X	5	X			3
5.0	0	X						X	
5.2	2			X		X	4		5
5.4	1				6			X	
5.6	1								7
5.8	0			X					
6.0	2		4		8			X	
6.2	1	X		X		X			4
6.4	3		7		7		5		
6.6	0							X	

TABLE 35

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /I/ TO MODEL 03/31/76.3

Interval	Number of PIH Peaks In This Interval	04/05/76.4/1		04/12/76.3/2		04/05/76.4/3		04/12/76.3/1	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.4	0			X					
1.6	1				4				
1.8	1								3
2.0	0	X						X	
2.2	3		2	X	2	X	1		
2.6	0			X			4		
2.8	1		4						
3.4	0	X							
3.6	0					X			
3.8	1								1
4.0	0	X				X		X	
4.2	3		1	X	1	X	2		
4.6	0	X		X		X			
4.8	0					X			
5.2	1		5						
5.6	0			X					
5.8	2		3						2
6.0	1	X		X	3	X		X	
6.2	1						3		
6.4	1								4
6.6	2	X			5		5		
6.8	1		5	X					
7.0	1				6				

TABLE 36

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /ɛ/ TO MODEL 03/31/76.3

Interval	Number of PIH Peaks In This Interval	04/05/76.4/1		04/15/76.3/2		04/05/76.4/3		04/15/76.3/1	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.6	2	X	2	X		X		X	5
1.8	2				2		1		
2.0	1								6
2.6	1		9						
2.8	1				9				8
3.2	3	X	3			X	3	X	2
3.4	1			X	1				
3.6	3		1	X		X	2		1
4.0	1				6				
4.2	1		8						
4.4	1								7
4.6	1				4				
4.8	1		5						
5.0	1	X		X			4		
5.2	3	X	4	X	3	X		X	4
5.8	1				8				
6.4	1		7						
6.6	2				6		5		
6.8	2	X	6					X	3
7.0	2			X	5	X	6		

TABLE 37

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /u/ TO MODEL 03/31/76.3

Interval	Number of PIH Peaks In This Interval	04/05/76.4/1		4/12/76.3/2		04/05/76.4/3		4/12/76.3/1	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
2.0	1								3
2.2	2			X	4	X	3		
2.4	2		1	X				X	2
2.6	2	X		X	1	X	2		
3.2	2				5		5		
3.6	1						7		
4.2								X	
4.6	2	X	2	X	2	X			
4.8	2					X	1	X	1
5.0	2	X	3	X	3				
5.2	1								4
5.6	3		4		6				5
5.8	1						6		
6.0	2		5		7				
6.6		X						X	
6.8	1			X		X	4		

TABLE 38

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /ə/ TO MODEL 03/31/76.3

Interval	Number of PIH Peaks In This Interval	3/31/76.3/4		4/15/76.3/2		04/05/76.4/2		04/15/76.3/1	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.0	3		8		9		9		
1.2		X		X		X			
1.6	3	X	5	X	2	X	4	X	
2.0	4		3		1		1		3
2.2		X						X	
2.8	3	X	1		5				2
3.0	1			X		X	1		
3.2	2		2					X	4
3.4	2				4		3		
3.6	1	X		X		X		X	7
3.8	0					X			
4.0	1					X			5
4.2	2		4	X			7		
4.4	2				3				1
4.6	0	X		X				X	
4.8	1					X	4		
5.2	2	X	7	X		X		X	7
5.4	2				6	X	8		
5.6	1							X	9
5.8	2		6		7			X	
6.0	1	X		X		X	6		
6.2	1								10
6.4	0					X			
6.6	1				8				
6.8								X	
7.0									6

TABLE 39

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /i/ TO MODEL 03/31/76.3

Interval	Number of PIH Peaks In This Interval	3/31/76.3/4		4/12/76.3/2		04/05/76.4		4/12/76.3/1	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.2	2		9		7				
1.4	2	X		X		X			6
1.6	2		4	X	6				
1.8	1								
2.2	2		5						
2.4	1	X		X	3	X			
2.6	2								4
3.2	0	X		X					
3.4	2	X				X	X		3
3.6	2		1		1				
3.8	1	X		X		X	X		
4.2	1		3						
4.4	1			X					5
4.6	1	X		X	8				
4.8	0	X				X			
5.0	2		8		4				
5.4	3		7		4				
5.6	0	X							
5.8	1	X	6	X		X			
6.0	2								2
6.2	1				9				
6.4	0	X	10						
6.6	1								

TABLE 40

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /o/ TO MODEL 03/31/76.3

Interval	Number of PIH Peaks In This Interval	3/31/76.3/4		04/15/76.3/2		04/05/76.4/2		04/15/76.3/1	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.0	1						9		
1.2	0	X		X		X			
1.4	2				7				7
1.6	0							X	
1.8	1	X	1	X		X			
2.0	2						1	X	5
2.2	1				3				
2.6	3	X	6				5		4
2.8	0			X		X		X	
3.0	0	X		X		X			
3.2	2				4		6	X	
3.6	3	X	2	X	1	X		X	1
3.8	1			X			2		
4.2	1		5						
4.6	3	X	3	X			3		3
4.8	1			X	2	X		X	
5.2	2	X		X			7		9
5.4	0			X		X			
5.6	3	X	7		6	X		X	5
6.0	1						8		
6.2	1							X	8
6.4	2	X	4	X			4		
6.6	1				5	X			
6.8	1								
7.0	0								2

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TABLE 41

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /r̩/ TO NEURON 710827/11

Interval	No. of Peak Occurrence In This Interval	710827/11/7		710827/11/14		710827/11/16		710827/11/9	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.2	1								2
1.6	3	X	1	X	7	X		X	1
1.8	1						8		
2.4	3	X	2	X	2	X	1	X	
2.6	1								3
2.8				X					
3.0	1				4				
3.2	2	X	3						4
3.4	1			X		X	4	X	
3.8	1								7
4.0	2	X		X	1	X	2	X	
4.2	1		6			X			
4.6	3		4		5		3		
4.8	1								6
5.0	2	X		X	3	X	4	X	
5.2						X			
5.4	1								5
5.6	3		5		6		4	X	
5.8		X		X		X			
6.2	1				7				
6.4	3		7				7		8
6.6		X						X	
6.8				X	9	X			

TABLE 42

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /æ/ TO NEURON 710827/11

Interval	No. of Peak Occurrence In This Interval	710827/11/6		710827/11/15		710827/11/17		710827/11/8	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.2	1	X		X		X		X	2
1.4	3		2		3		6		
2.0	2		7			X			7
2.4	0	X				X		X	
2.6	3	X	2	X		X	3		4
2.8	1				1				
3.2	1					X			9
3.4	2		1		2				
3.6	1						1		
3.8	1	X		X		X		X	1
4.0	1		5						
4.2	1						5		
4.4	0					X			
4.6	1		9						
4.8	1				4				
5.0	3	X	4				2	X	2
5.2	0			X		X			
5.6	0					X			
5.8	1								6
6.0	1						4		
6.2	2		6						5
6.4	1	X		X	5	X		X	
6.6	2		8						8

TABLE 43

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /ɔ/ TO NEURON 710827/11

Interval	No. of Peak Occurrence In This Interval	710827/11/7		710827/11/14		710827/11/16		710827/11/9	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.4	3		1				7	X	1
1.6	1	X		X	1			X	
2.0				X				X	
2.2	1	X							4
2.4	2		2	X	3			X	
2.6	2						3	X	5
3.0		X						X	
3.2				X				X	
3.4								X	
3.6	3	X	3	X		2		X	2
3.8				X					
4.0	1						1	X	
4.6	1					6			
4.8	1		4			4			
5.0	2	X						X	3
5.2	1	X		X			2	X	
5.4								X	
5.8	1	X		X			4	X	
6.0								X	
6.2	3		5			5	5	X	
6.4								X	
6.6	2	X		X			6		6

TABLE 44

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /a/ TO NEURON 710827/11

Interval	No. of Peak Occurrence In This Interval	710827/11/6		710827/11/15		710827/11/17		710827/11/8	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.2	2	X	4	X		X		X	1
1.4	1						8		
1.8	1				5				
2.0	2		4						6
2.2	2	X		X	6	X	4	X	
2.4			6						
2.6	0	X		X		X		X	
2.8	3		1		3			X	4
3.0	1						1		
3.2	0	X						X	
3.6	1								5
3.8	2	X	2				2	X	
4.0	2			X	1	X		X	2
4.6	1						3		
4.8	3		3	X	1	X			2
5.0	1	X					7	X	
5.2	0			X		X			
5.4	0							X	
5.6	1		7						
5.8	3			X	4		5		
6.0	0							X	7
6.2	1	X		X		X	6		
6.6	1							X	
6.8	1		8		7			X	8

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Interval	No. of Peak Occurrence In This Interval	710827/11/6		710827/11/14		710827/11/17		710827/11/9	
		SIH.	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.2	2		3						1
1.4				X					
2.0	2	X	1		2			X	
2.2	2			X		X	5		2
2.4	1				2				8
2.6	2			X			4		
2.8	1		5						
3.0	1				6				
3.2	1		4						
3.4	2	X			8				3
3.6						X			
3.8	3		2		4		2		
4.0		X				X		X	
4.2	2			X	1				5
4.6	2	X		X		X	5		5
4.8						X			
5.0	2		7		9				
5.2	1						3		
5.4	1				6				
5.6	1			X					3
5.8	2		5				5		
6.0	1	X		X	4	X		X	
6.2	2						8		5
6.6	1	X					9		
6.8	1		8	X					
7.0	2				9		1		

TABLE 46

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR
THE FOUR PRESENTATIONS OF THE VOWEL /ɛ/ TO NEURON 710827/11

Interval	No. of Peak Occurrence In This Interval	710827/11/6		710827/11/15		710827/11/17		710827/11/8	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.4	2		1		7				2
1.6	1	X		X		X	7	X	
2.0	2				4		6		
2.2	1								1
2.8	3		6		2		7		
3.0	1								6
3.2	0	X				X		X	
3.4	2		4	X			2		
3.6	0			X		X			
3.8	2				3		3		
4.4	1		7						
4.6	1								2
4.8	0						4		
5.0	0	X		X					
5.2	2	X	2	X	1	X		X	
5.4	2						5		7
5.8	3		2		5				5
6.0	1						9		
6.2	1				5				
6.8	2	X			7		1	X	
7.0	2		4						2

TABLE 47

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /u/ TO NEURON 710827/11

Interval	No. of Peak Occurrence In This Interval	710827/11/6		710827/11/14		710827/11/17		710827/11/9	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.2	1								1
1.4	1		6						
1.8	2				2				1
2.0	1		1						
2.2	2			X		X	4		1
2.4	2		2		7			X	
2.6		X		X		X			
2.8	2		4						5
3.0	1						5		
3.2	1								7
3.6	3		5		4		7		
3.8	1								4
4.2	2		2				2	X	
4.6		X		X		X			
4.8	2				1	X	2	X	
5.0	1	X		X					10
5.2	1		6						
5.4	2				5				11
5.8	2						7		9
6.0	1		9						
6.2	2				2				6
6.4	2		10				6		
6.6		X						X	
6.8	2		8	X					8
7.0	2				6		1		

TABLE 48

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /ə/ TO NEURON 710827/11

Interval	No. of Peak Occurrence In This Interval	710827/11/7		7/0827/11/15		710827/11/16		710827/11/8	
		SIH.	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.2	3	X	3	X		X	8		1
1.4	1				8				
1.6	0	X		X		X		X	
1.8	3		2				7		1
2.0	1				7				
2.2	0	X						X	
2.6	2		1		1				
2.8	2	X					2		3
3.0	0			X		X			
3.2	0							X	
3.4	1								7
3.6	3	X	5	X	2	X	1	X	
3.8	0					X			
4.2	1			X	2	X			
4.4	2						4		4
4.6	1	X	7	X				X	
4.8	0					X			
5.2	3	X	8	X	4		5	X	
5.4	1					X			8
5.6	0							X	
5.8	1							X	4
6.0	3	X	3	X	5	X	3		
6.2	0								
6.4	2				6	X			
6.8	1						6	X	
7.0	1								6

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TABLE 49

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /i/ TO NEURON 710827/11

Interval	No. of Peak Occurrence In This Interval	710827/11/7		710827/11/14		710827/11/16		710827/11/9	
		SIH.	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.2	2		5	X					2
1.4	1	X		X		X	7		
1.8	3		2				5		6
2.0	1				3				
2.4	2	X		X		X	4		11
2.6	1				3				
2.8	2		6						1
3.0	1						6		
3.2	0	X		X					
3.4	0	X				X		X	
3.6	3		8		6				2
3.8	0	X		X		X		X	
4.0	1						7		
4.2	2		7						8
4.4	0			X					
4.6	1	X		X					6
4.8	0	X				X			
5.0	1								12
5.4	2				1				8
5.6	1	X	3						
5.8	0	X		X		X			
6.0	2		4		3				
6.2	2						1		4
6.4	0	X							
6.6	1						3		8
7.0	4		1				1		5

TABLE 50

SIH PEAK LOCATIONS AND PIH PEAK LOCATIONS AND RANKS FOR THE FOUR PRESENTATIONS OF THE VOWEL /o/ TO NEURON 710827/11

Interval	No. of Peak Occurrence In This Interval	710827/11/7		710827/11/15		710827/11/16		710827/11/8	
		SIH	PIH	SIH	PIH	SIH	PIH	SIH	PIH
1.2	1	X		X		X			2
1.4	2		3		8				
1.6	1						8	X	
1.8	2	X		X	5	X			6
2.0	1		5					X	
2.2	1						2		
2.4	3		1		2				5
2.6	0	X							
2.8	0			X		X		X	
3.0	2	X		X		X	7		4
3.4	1				1				
3.6	2	X	2	X		X	1	X	
3.8	1			X					1
4.4	2				2		5		
4.6	1	X	6	X					
4.8	1			X		X		X	8
5.2	0	X							6
5.4	1			X		X			
5.6	1	X	4			X		X	
5.8	2				4		3		8
6.0	1								
6.2	2				7				
6.4	1	X		X			4	X	2
6.6	1		7			X			
6.8	2				6		6		
7.0	0								

Figure 60. Average Fraction of Misplaced Peaks for Ten Vowels for both the Neuron and the Model, Neuron 710827/11, Model 03/31/76.3.

The following general rules can be deduced from the figure and the fraction of misplaced peaks computations:

(1) The SIH is a predictor of vowel PIH peaks. Accuracy ranges from 0% to 57% misplaced peaks.

(2) The accuracy of the prediction is inversely related to the distance from the Neuron's characteristic frequency to the vowel formant closest to it.

(3) The SIH is a more accurate predictor of Model vowel PIHs.

8.6 VERIFICATION OF THE MODEL USING THE "FRACTION OF MIS-PLACED PEAKS" METRIC

An eyeball correlation of the comparable vowel PIHs of the Neuron and the Model leaves one with the impression that there are differences between them. But there are also differences between Neuron vowel PIHs generated from the Neuron's responses to stimuli of the same intensity. The question addressed in this section is: Are the differences between the comparable Neuron and Model vowel PIH pairs no greater than the differences between Neuron vowel PIH pairs generated from the Neuron's responses to stimuli of the same intensity? An affirmative answer to this question is a verification of the model.

The metric used to measure differences between vowel PIHs is the fraction of misplaced peaks, which is defined as the ratio of the number of peaks that do not match in the vowel PIH pair and the total number of peaks. All peaks must occur at an interpulse interval of 7 msec or less. A match is defined as in the previous section.

The Peak Occurrence Tables were used to generate the fraction of misplaced peaks for Neuron - Neuron pairs for those runs were the vowels were presented at equal intensity (the two 10 dB runs). The calculations are presented in Table 51. The calculations for the fraction of misplaced peaks for the Neuron-Model vowel PIH pair comparison are presented in Tables 52 through 61.

If the Neuron-Neuron fraction of misplaced peaks values are used as the benchmarks, the vowels /ṛ/, /æ/, /I/, /$\mathcal{E}$/, /u/, and /ə/ have at least one vowel PIH that can not be distinguished from the comparable Neuron vowel PIH. /o/ also has some very low values, even though they are not less than the /o/ benchmark. The Model can, therefore, be considered at least partially validated for six or seven of the ten vowels.

8.7 VOWEL PIH SHAPE COMPARISON

The Peak Occurrence Tables reveal that the probability associated with coincident peaks of comparable Neuron vowel PIH pairs can vary by 50% or more, even for those pairs that were generated from responses to the same stimulus at the same intensity. Tables 52 through 61 were created to quantify this observation. The description for the procedure used to create these tables will be in terms of the vowel /ṛ/.

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TABLE 51

COMPARISON OF VOWEL PIHS IN TWO RUNS OF THE
SAME STIMULUS AND INTENSITY, NEURON 710827

Vowel	Run A	Run B	Number Peaks		Number Matching Peaks	Number Mismatched Peaks	Fraction Mismatched Peaks
			Run A	Run B			
/ɪ̈/	7	14	7	8	7	1	0.07
/æ/	6	15	9	5	5	4	0.29
/ɔ/	7	14	5	6	6	0	0.00
/a/	6	15	8	7	7	1	0.07
/I/	6	14	9	10	8	3	0.16
/ɛ/	6	15	7	8	5	5	0.33
/u/	6	14	11	7	8	3	0.17
/ə/	7	15	8	8	7	2	0.13
/i/	7	14	9	6	6	3	0.20
/o/	7	15	7	8	7	1	0.07

TABLE 52

COMPARISON OF PEAKS IN MODEL AND NEURON
/r/-PIHS USING THE FRACTION OF MISPLACED PEAKS METRIC

Neuron Run	Model Run	Total Number Peaks	Number Matching Peaks	Fraction Mismatched Peaks
7	03/31/76.3/4	14	6	0.14
14	04/12/76.3/2	18	8	0.11
16	04/05/76.4/2	15	6	0.20
9	04/12/76.3/1	19	9	0.10

TABLE 53

COMPARISON OF PEAKS IN MODEL AND NEURON
/æ/-PIHS USING THE FRACTION OF MISPLACED PEAKS METRIC

Neuron Run	Model Run	Total Number Peaks	Number Matching Peaks	Fraction Mismatched Peaks
6	04/05/76.4/1	15	6	0.20
15	04/15/76.3/2	12	4	0.33
17	04/05/76.4/3	11	4	0.27
8	04/15/76.3/1	16	7	0.06

TABLE 54

COMPARISON OF PEAKS IN MODEL AND NEURON /ɔ/-PIHS USING THE FRACTION OF MISPLACED PEAKS METRIC

Neuron Run	Model Run	Total Number Peaks	Number Matching Peaks	Fraction Mismatched Peaks
7	03/31/76.3/4	12	3	0.50
14	04/12/76.3/2	12	3	0.50
16	04/05/76.4/2	14	5	0.36
9	04/12/76.3/1	17	7	0.24

TABLE 55

COMPARISON OF PEAKS IN MODEL AND NEURON /a/-PIHS USING THE FRACTION OF MISPLACED PEAKS METRIC

Neuron Run	Model Run	Total Number Peaks	Number Matching Peaks	Fraction Mismatched Peaks
6	04/05/76.4/1	16	7	0.19
15	04/15/76.3/2	16	6	0.25
17	04/05/76.4/3	16	6	0.31
8	04/15/76.3/1	15	5	0.40

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TABLE 56

COMPARISON OF PEAKS IN MODEL AND NEURON
/I/-PIHS USING THE FRACTION OF MISPLACED PEAKS METRIC

Neuron Run	Model Run	Total Number Peaks	Number Matching Peaks	Fraction Mismatched Peaks
6	04/05/76.4/1	16	7	0.13
14	04/12/76.3/2	17	5	0.47
17	04/05/76.4/3	14	4	0.43
9	04/12/76.3/1	12	2	0.67

TABLE 57

COMPARISON OF PEAKS IN MODEL AND NEURON
/ε/-PIHS USING THE FRACTION OF MISPLACED PEAKS METRIC

Neuron Run	Model Run	Total Number Peaks	Number Matching Peaks	Fraction Mismatched Peaks
6	04/05/76.4/1	16	6	0.31
15	04/15/76.3/2	17	7	0.29
17	04/05/76.4/3	15	7	0.20
8	04/15/76.3/1	15	7	0.13

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TABLE 58

COMPARISON OF PEAKS IN MODEL AND NEURON
/u/-PIHS USING THE FRACTION OF MISPLACED PEAKS METRIC

Neuron Run	Model Run	Total Number Peaks	Number Matching Peaks	Fraction Mismatched Peaks
6	04/05/76.4/1	16	3	0.63
14	04/12/76.3/2	16	8	0.13
17	04/05/76.4/3	16	6	0.25
9	04/12/76.3/1	17	6	0.41

TABLE 59

COMPARISON OF PEAKS IN MODEL AND NEURON
/ə/-PIHS USING THE FRACTION OF MISPLACED PEAKS METRIC

Neuron Run	Model Run	Total Number Peaks	Number Matching Peaks	Fraction Mismatched Peaks
7	03/31/76.3/4	17	7	0.24
15	04/15/76.3/2	16	7	0.13
16	04/05/76.4/2	18	9	0.06
8	04/15/76.3/1	18	8	0.17

TABLE 60

COMPARISON OF PEAKS IN MODEL AND NEURON
/i/-PIHS USING THE FRACTION OF MISPLACED PEAKS METRIC

Neuron Run	Model Run	Total Number Peaks	Number Matching Peaks	Fraction Mismatched Peaks
7	03/31/76. 3/4	18	7	0.22
14	04/12/76. 3/2	15	5	0.33
16	04/05/76. 4/2	18	7	0.22
9	04/12/76. 3/1	18	6	0.33

TABLE 61

COMPARISON OF PEAKS IN MODEL AND NEURON
/o/-PIHS USING THE FRACTION OF MISPLACED PEAKS METRIC

Neuron Run	Model Run	Total Number Peaks	Number Matching Peaks	Fraction Mismatched Peaks
7	03/31/76. 3/4	14	6	0.14
15	04/15/76. 3/2	15	6	0.27
16	04/05/76. 4/2	17	6	0.29
8	04/15/76. 3/1	18	8	0.11

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The "Number of PIH Peaks in this Interval" column of Tables 31 and 41 was examined for one of the following situations:

(1) an entry of 4;

(2) an entry of 3, with an adjacent interpulse interval (adjacent in terms of sample interval) having an entry of 1 or more. All four runs must contain peaks in these intervals.

(3) An entry of 2, with an adjacent interpulse interval having an entry of two or more. All four runs contain peaks in these intervals.

(4) An entry of 2, with the two adjacent interpulse intervals have an entry of one or more. All four runs must contain peaks in these intervals.

The range of interpulse intervals for either the Model (Table 31) or the Neuron (Table 42) that satisfy any one of these conditions are entered in the "Interpulse Intervals" column of Table 62. Entries are made in the Neuron or Model columns according to whether the corresponding interpulse interval range was obtained from Table 31 or Table 41. The mean and standard deviation entries are obtained by computing those statistics on the ranks of the peaks contained in the interpulse interval range of the appropriate table.

Tables 62 through 71 provide a quantitative description of the variation in shape, on a Neuron to Neuron, Model to Model, and Model to Neuron basis, of the four vowel PIH's associated with each vowel.

For the Neuron to Neuron comparison, the number of interpulse interval ranges associated with the Neuron is directly proportional to the similarity in the shape of the vowel PIHs. Furthermore, the standard deviation values indicate the degree of variability in the rank of the peaks occurring in the interpulse interval ranges. Similar statements can be made for the Model to Model comparison. Reflection on these values led to the conclusion that there is considerable variation in the shapes of the Neuron vowel PIHs for a single vowel and generally less variation in the shapes of the Model vowel PIHs. Therefore, a metric for validation based on PIH shape was not feasible.

For the Model to Neuron comparison, the number of interpulse interval ranges that overlap between the two cases can be used to indicate the degree of Model-Neuron Vowel PIH similarity. The means can be compared to determine the shape variation between Neuron and Model PIHs. For instance, the /r/-vowel PIHs of the Model have more strength around the 3.4 to 4.2 msec range of interpulse intervals than the /r/-vowel PIHs of the Neuron and less strength in the 2.4 to 2.6 msec range.

These tables will be used extensively in the next phase of the modeling effort.

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TABLE 62

/r/-PIH SHAPE COMPARISON

Interpulse Intervals	Neuron		Model	
	Mean	Standard Deviation	Mean	Standard Deviation
1.6 - 1.8	4.25	3.77	2.25	0.50
2.4			5.50	1.00
2.4 - 2.6	2.00	0.82		
3.0 - 3.4	3.75	0.50		
3.4 - 3.6			1.00	0.00
3.8 - 4.2	4.00	2.94		
4.0 - 4.2			2.50	0.58
4.6 - 4.8	4.50	1.29		
5.0 - 5.2			4.25	0.50
5.4 - 5.6	5.00	0.82		
5.6 - 5.8			5.25	0.50
6.4	7.25	0.50		
6.6 - 7.0			7.00	0.00

TABLE 63

/æ/-PIH SHAPE COMPARISON

Interpulse Intervals	Neuron		Model	
	Mean	Standard Deviation	Mean	Standard Deviation
1.2 - 1.4	3.25	1.89	3.75	0.96
2.4 - 2.6			1.50	1.00
2.6 - 2.8	2.50	1.29		
3.4 - 3.8	1.25	0.50		
3.8			1.75	0.50
4.8 - 5.0	3.00	1.15		
5.0 - 5.2			3.50	1.00
6.0 - 6.4	5.00	0.82		
6.2 - 6.4			4.25	0.96

TABLE 64

/ɔ/-PIH SHAPE COMPARISON

Interpulse Intervals	Neuron		Model	
	Mean	Standard Deviation	Mean	Standard Deviation
1.2 - 1.4			5.00	1.41
2.0 - 2.2	5.00	1.15		
2.4 - 2.6			1.75	0.50
2.8 - 3.0	2.25	1.50		
3.8 - 4.0	1.75	0.50	1.25	0.50
4.6 - 4.8	2.25	0.96	4.25	2.22
5.6 - 5.8	5.75	1.50		
6.2 - 6.4			5.75	1.50
6.6 - 7.0	7.67	0.58		

/a/-PIH SHAPE COMPARISON

Interpulse Intervals	Neuron		Model	
	Mean	Standard Deviation	Mean	Standard Deviation
1.4 - 1.6	2.50	3.00	4.50	2.08
2.0			3.30	0.58
2.4 - 2.6	3.25	1.26		
3.0 - 3.2			4.00	0.82
3.6	2.50	0.58		
3.6 - 3.8			1.00	0.00
4.8 - 5.2	3.25	0.96		
5.0 - 5.4			3.60	1.82
6.2	5.00	0.00		

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TABLE 66

/I/-PIH SHAPE COMPARISON

Interpulse Intervals	Neuron		Model	
	Mean	Standard Deviation	Mean	Standard Deviation
2.0 - 2.2	2.75	1.71		
2.2			1.67	0.58
3.8	2.67	1.15		
4.2			1.33	0.58
5.8 - 6.2	5.00	0.82	2.75	0.50
6.4 - 6.8			4.75	0.50

TABLE 67

/ɛ/-PIH SHAPE COMPARISON

Interpulse Intervals	Neuron		Model	
	Mean	Standard Deviation	Mean	Standard Deviation
1.4 - 1.6	4.25	3.20		
1.6 - 1.8			2.50	1.73
2.8 - 3.0	5.25	2.22		
3.2			2.67	0.58
3.4 - 3.6	1.25	0.50		
5.0 - 5.2			3.75	0.50
5.2 - 5.4	3.75	2.75		
5.8 - 6.0	5.25	2.87		
6.8 - 7.0	3.50	2.65	5.00	1.41

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TABLE 68

/u/-PIH SHAPE COMPARISON

Interpulse Intervals	Neuron		Model	
	Mean	Standard Deviation	Mean	Standard Deviation
1.8 - 2.0	1.33	0.58		
2.0 - 2.2	2.00	1.73		
2.2 - 2.4			2.50	1.29
3.6 - 3.8	5.00	1.41		
4.8 - 5.0	3.75	4.19	2.25	1.50
5.2 - 5.4	7.67	3.06		
5.6 - 5.8			6.25	0.96
6.2 - 6.4	7.50	4.36		
6.8 - 7.0	6.00	3.56		
7.2			3.75	0.96

TABLE 69

/ə/-PIH SHAPE COMPARISON

Interpulse Intervals	Neuron		Model	
	Mean	Standard Deviation	Mean	Standard Deviation
1.0			8.67	0.58
1.2 - 1.4	5.00	3.56		
1.6			3.67	1.53
1.8 - 2.0	4.25	3.20		
2.0			2.00	1.15
2.6 - 2.8	1.75	0.96		
2.8 - 3.0			2.25	1.89
3.2 - 3.4			3.25	0.96
3.4 - 3.6	3.75	2.75		
4.2 - 4.4			3.75	2.50
4.2 - 4.6	4.25	2.06		
5.2 - 5.4	6.25	2.06	7.00	0.82
5.8 - 6.0	3.75	0.96		

TABLE 70

/i/-PIH SHAPE COMPARISON

Interpulse Intervals	Neuron		Model	
	Mean	Standard Deviation	Mean	Standard Deviation
1.2 - 1.6			6.00	1.63
1.8 - 2.0	4.00	1.83		
2.2 - 2.6			4.50	1.29
3.4 - 3.6			1.50	1.00
3.6	5.33	3.06		
5.4			4.67	2.08
5.8 - 6.2			6.50	3.32
6.0 - 6.2	3.00	1.41		
7.0 - 7.2	2.25	1.89	2.25	1.26

TABLE 71

/o/-PIH SHAPE COMPARISON

Interpulse Intervals	Neuron		Model	
	Mean	Standard Deviation	Mean	Standard Deviation
2.2 - 2.4	2.50	1.73		
2.6			4.67	1.53
3.4 - 3.8	1.25	0.50		
3.6 - 3.8			1.33	0.58
4.6 - 4.8			2.50	0.58
5.6			5.67	1.53
6.2 - 6.6			5.00	1.41

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The "Number of PIH Peaks in this Interval" column of Tables 31 and 41 was examined for one of the following situations:

(1) an entry of 4;

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These tables will be used extensively in the next phase of the modeling effort.

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